THE STRUCTURE OF SEX WORK: VARIABILITY IN THE NUMBERS AND TYPES OF SEX PARTNERS OF FEMALE SEX WORKERS IN SOUTHERN INDIA

by

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ABSTRACT

Background and objectives: There is limited knowledge of sexual structure (i.e., the numbers, types and distributions of sex partners and patterns of sexual contact) and its relationship with HIV infection and prevention among female sex workers (FSWs). The objectives of this study were therefore: to examine the social and environmental factors associated with the numbers of clients of FSWs; to characterize heterogeneity in sexual structure and assess how sexual structure influences HIV prevalence; and to examine the impact of an HIV intervention on condom use by different partners (clients, intimate partners), as reported by FSWs.

Methods: This study used data collected from FSWs and clients in Karnataka state, southern India as part of the Avahan AIDS Initiative, an ongoing large-scale HIV intervention. Bivariate and multivariable statistical techniques were used to examine the relationships between two outcomes (numbers of clients and condom use) and key social and environmental factors, including exposure to the Avahan intervention. A deterministic compartmental mathematical model was developed to understand how sexual structure influenced HIV prevalence on a population level.

Results: Sexual structure displayed substantial geographic variation across districts in Karnataka. The most common predictors of higher rates of clients were a reliance on sex work as sole income, younger age, and being single or cohabiting as compared to married. The effect of the solicitation environment (e.g., brothels, public places, homes) varied by district. Intervention exposure was associated with increased condom use by FSWs' clients, but not their intimate partners. Mathematical modelling identified sexual structure parameters with the largest influence on increasing (numbers of clients of FSWs; numbers of visits to FSWs by clients;

frequency of sex acts with repeat clients) and decreasing (duration of the repeat FSW-client partnership; fraction of repeat clients) HIV prevalence within and across districts.

Conclusions: Differences in the sexual structure of FSWs and their commercial clients have important implications for HIV transmission dynamics. In light of findings related to both differences in sexual structure across districts and the impact of an intervention on condom use by different partners of FSWs, HIV prevention planners need to tailor interventions to respond to local contexts.

PREFACE

This statement is to certify that the work presented in this thesis was conceived, conducted, written, and disseminated by Kathleen Nicole Deering (KND). All research described in this dissertation was approved by the University of British Columbia Research Ethics Board; certificate number H08-02450. The co-authors of the manuscripts, including Dr. Jean A Shoveller (JAS), Dr. Marie-Claude Boily (MCB), Dr. Mark W Tyndall (MWT), Dr. Mieke Koehoorn (MK), Dr. Stephen Moses (SM), Dr. James F Blanchard (JFB), Dr. Michel Alary (MA), Dr. Catherine Lowndes (CL), Dr. Peter Vickerman (PV), Dr. Michael Pickles (MP), Janet Bradley (JB), Mr. Souradet Y Shaw (SYS), Dr. BM Ramesh (BMR), Dr. Shajy Isac (SI), Dr. Reynold Washington (RW) and Kaveri Gurav (KG) made contributions only as is commensurate with committee, collegial or co-author duties. The principal investigators of the larger research program from which the studies in this dissertation were derived were SM and JFB, and MA; therefore, they had access to all of the data and as collaborating authors take full responsibility for the integrity of the results and accuracy of the data. With advice from supervisor JAS and committee member MCB, KND designed the studies and wrote the research protocols. With guidance and input from JAS, MCB, MA, CL and SYS, KND designed the research and conducted the statistical analysis described in Chapters 3 through 5. KND conducted the review described in Chapter 2. Significant scientific input and approval of the final manuscript for submission was provided by the following co-authors to the relevant chapters: JAS, MCB, MWT, SM, JFB, SYS, BMR and SI to Chapter 3; and JAS, MCB, MK, SM, JFB, SYS, BMR and SI to Chapter 4. JAS, MCB, MWT, CL, PV, JB, MP, KG, SM, BMR, RW and MA contributed substantial technical and methodological input to Chapter 5 and approved the final version of the related manuscript for submission. JAS, MCB, MWT and MK provided intellectual content that contributed to Chapter 6. All manuscripts contained in this thesis were prepared and written by KND. Final drafts of the manuscripts were prepared following the inclusion of material based on comments from co-authors, the journal editors and external peer reviewers. The following publications arose from work presented in Chapter 3 and 5 of this dissertation, respectively.

Chapter 3

Deering, KN, Boily, M-C, Lowndes, C, Shoveller, J, Tyndall, MW, Vickerman, P, Bradley, J, Gurav, K, Pickles, M, Moses, S, Ramesh, BM, Washington, R, Alary, M. A dose-response relationship between exposure to a large-scale core group HIV prevention intervention and consistent condom use with different sex partners of female sex workers in southern India. *BMC Public Health* (*submitted*).

Chapter 5

Deering K, Tyndall MW, Shoveller J, Moses S, Blanchard JF, Shaw SY, Ramesh, BM, Isac, S, Boily, M-C. Factors associated with numbers of client partners of female sex workers across five districts in southern India. *Sexually Transmitted Diseases* 2010, 37:687-695.

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LIST OF ABBREVIATIONS

AIDS	Acquired Immune Deficiency Syndrome
Avahan	The Avahan AIDS Initiative
CHARME	Centre hospitalier *afflilié* universitaire de Québec HIV/AIDS Monitoring & Evaluation Team – India
FSW	Female Sex Worker
HIV	Human Immunodeficiency Virus
IBBA	Integrated Biological and Behavioural Assessments
KHPT	Karnataka Health Promotion Trust
MSM	Men Who Have Sex With Men
SBS	Special Behavioural Surveys

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Finally, I would like to thank my husband, David Gaertner, and my family and friends for their unwavering love and support throughout this process.

DEDICATION

To my husband,

DAVID GAERTNER

CHAPTER 1

BACKGROUND, RATIONALE AND OBJECTIVES

1.1 AN INTRODUCTION TO SEXUAL STRUCTURE

The sexual structure of a population can be conceptualized as the numbers, types and distributions of individuals' sex partners, and the sex partnering patterns[1] between individuals. Research on the transmission dynamics of HIV has recognized and demonstrated the importance of heterogeneity of some features of sexual structure. Patterns of human sexual behaviour demonstrate heterogeneity. Populations are comprised of many sub-groups with different levels and types of sexual activity, which can often impact HIV epidemic trajectories [Anderson and May 1991, Anderson et al., 1991]. Sub-groups may also be defined by the type of sex partners individuals have (e.g., heterosexual versus same-sex partners; regular/long-term sex partners versus occasional sex partners; commercial sex partners versus non-commercial sex partners). On a population level, the establishment and spread of epidemics of infections with a low infectivity, such as HIV, has been shown to depend on the existence of smaller sub-groups of individuals "who have a level of risk behaviour sufficient to generate viable chains of transmission in a population and in absence of which the infection would die out" [Boily et al., 2002, page i78]. This small group is frequently termed a 'core group' [Anderson and May 1991]. Female sex workers (FSWs) are often considered a core group in HIV transmission because of their high rates of partner change. Commercial sex has been identified as playing an important role in HIV epidemics in various settings, including southern India [Lowndes et al.,

[1]The term 'sex partnering patterns' will be conceptualized in this thesis as 'patterns of sexual contact between female sex workers and their sex partners'; these terms will be used interchangeably throughout this thesis.

2002, Lowndes et al., 2008, Vickerman et al., 2010]. The potential of the infection to move rapidly beyond core groups to a wider population depends on the level of sexual linkage between core groups and bridge populations (e.g., individuals with sex partners from both core groups and the wider population) as well as the latter with the more general population [Anderson and May 1991]. Heterogeneity in sexual structure also has been demonstrated to exist *within* and *across* FSWs and their partners. It has been hypothesized that this heterogeneity could help explain differences in HIV prevalence across FSW sub-groups (including across geography), and influence the effectiveness of interventions in these high-risk populations [Blanchard et al., 2007, Blanchard et al., 2008b, Blanchard and Aral 2010, Boily 2009].

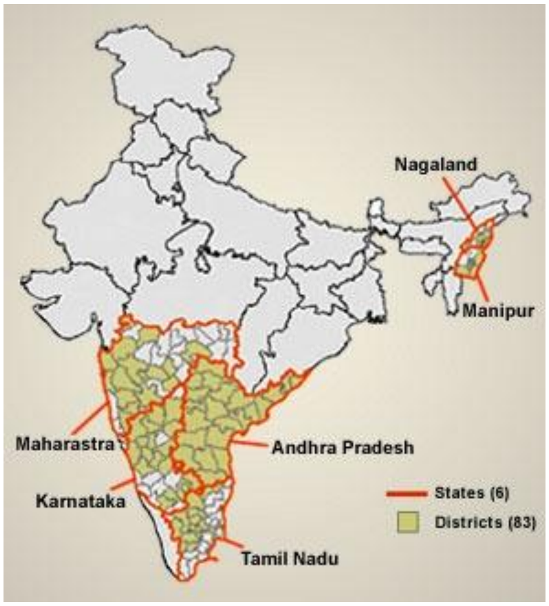
1.2 HIV AND SEX WORK IN SOUTHERN INDIA

The HIV epidemic in India is highly heterogeneous across geography [HIV Sentinel Surveillance and HIV Estimation in India 2007 A Technical Brief 2008]. The state of Karnataka, located in southern India, is one of six states in India with the highest HIV prevalence (Figure 1.1a). In 2007, overall adult HIV prevalence in Karnataka was estimated to be 0.7% as compared to an overall adult prevalence in India of 0.3% [HIV Sentinel Surveillance and HIV Estimation in India 2007 A Technical Brief 2008, NIMS & NACO, 2004 2004]. While India's overall adult prevalence appears low compared to some countries in sub-Saharan Africa (e.g., Botswana at 38.8% in 2003 and 24.1% in 2005) [UNAIDS epidemic update 2007 2007, UNAIDS epidemic update 2009 2009], a low prevalence still results in a large number of infected individuals due to India's large population size (~1 billion people). Moreover, the Indian HIV epidemic appears to be concentrated in particular regions and especially amongst high-risk groups, including FSWs. Based on available evidence, sex work is believed to play a large role in the HIV epidemic in southern India, including in Karnataka state, where the virus is thought to be transmitted predominantly through heterosexual sex [Arora et al., 2004, Vickerman et al., 2010]. Women who engage in sex work in southern India are highly vulnerable to becoming HIV positive and/or becoming infected with sexually transmitted infections (STIs) [HIV Sentinel Surveillance and HIV Estimation in India 2007 A Technical Brief 2008, Ramesh et al., 2008, Ramesh et al., 2010]. This population also experiences high rates of poverty, stigmatization, violence and exploitation, as well as low literacy rates and poor access to healthcare services [Blanchard et al., 2005, Cornish 2006, Dandona et al., 2006, Gangoli 2006]. Although some state-level surveillance data seem to suggest that HIV prevalence among FSWs in Karnataka state decreased to 5.3% in 2007 from 14.4% in 2003 [HIV Sentinel Surveillance and HIV Estimation in India 2007 A Technical Brief 2008][2], HIV prevalence has been observed to be much higher in specific districts (sub-state administrative areas). Due to their higher prevalence rates, these districts were selected as the implementation sites for the Avahan AIDS Initiative (Figure 1.1b), a large-scale, core group, HIV prevention initiative in India [Avahan, the India AIDS Initiative - the Business of HIV prevention at Scale 2008]. Based on data gathered during the Integrated Biological and Behavioural Assessments (IBBA[3]) conducted as part of the Monitoring and Evaluation of the Avahan AIDS Initiative, HIV prevalence among FSWs varied from 9.7% in Shimoga district to 33.9% in Belgaum district in 2004-05 and from 8.0% to 27.3% in Bangalore and Belgaum district, respectively, in 2007-08 (Figure 1.2). Much of the heterogeneity in HIV prevalence among FSWs between these geographic regions remains unexplained.

[2] Refer to footnote 1 on page 1 of this reference regarding surveillance methods.
[3] All output data from the IBBA in Chapter 1 were calculated for the purposes of this dissertation, although some of the output may appear in other published manuscripts or reports.

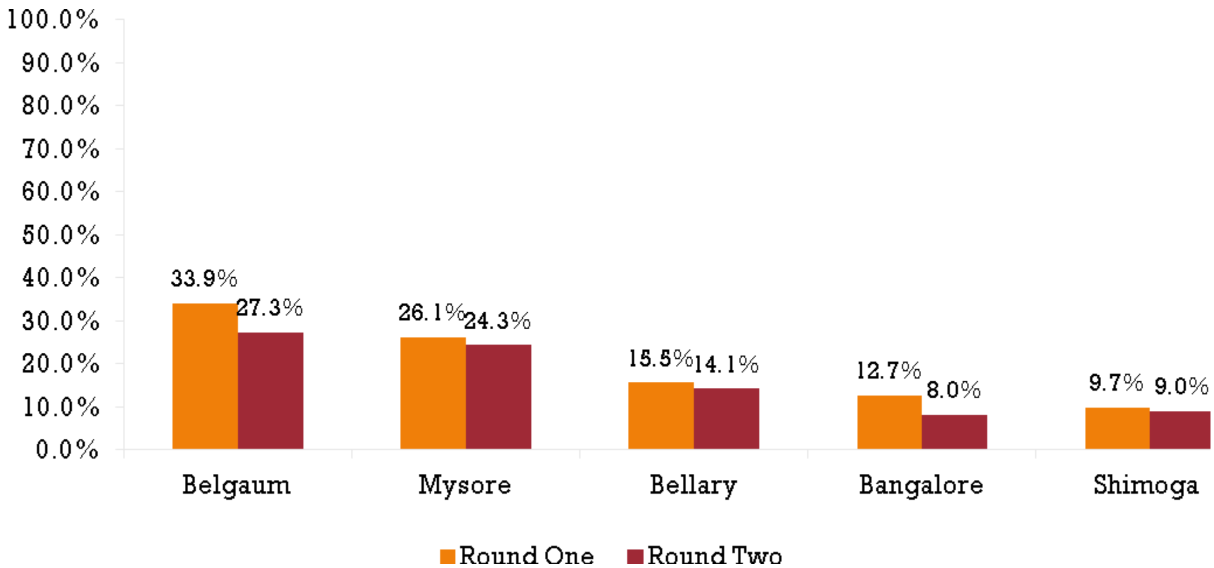
Figure 1.1: Maps describing the locations in Karnataka state, India from which the data for the analysis in this dissertation were drawn, including:

(a) A map of the six states with the highest HIV prevalence in India. Karnataka state is highlighted.



(b) A detailed map of districts in Karnataka state, India. The five districts from which the data for the analyses in this dissertation were drawn (Bangalore, Belgaum, Bellary, Shimoga and Mysore) are underlined.

Figure 1.2: HIV prevalence in Round 1 (2004-05) and Round 2 (2007-08) of the Integrated Biological and Behavioural Assessments in Karnataka state, India.[1]



[1]The Avahan AIDS Initiative was introduced in 2003.

1.3 ENVIRONMENTS OF HIV RISK FOR SEX WORKERS

The social and environmental contexts of FSWs have important implications for the characteristics of local sex work practices (e.g., age at entry in sex work; women's economic dependence on sex work for income), sexual structure, and FSWs' vulnerability to acquisition and transmission of STIs and HIV [Aral et al., 2006, Blanchard 2009, Dandona et al., 2006]. The vulnerability of FSWs to HIV is due to many factors, including gender-based inequities such as those surrounding women's financial independence, cultural practices that restrict women from working outside the home and gender gaps in terms of education, literacy and employment [Chen and Dreze 1992, Chen 2001, Dandona et al., 2006]. Table 1.1 describes some relevant characteristics of the study population. In Karnataka (2004-05), the majority of women (79.1% in Bellary district to 87.5% in Belgaum) reported that they initiated sex work because they "wanted a better life". Most of the remaining women reported that they had been deserted by their husbands or widowed (Table 1.1). Women who have been deserted by their husbands or widowed are particularly economically vulnerable in India, due to restricted inheritance rights of their husbands' land and belongings [Chen and Dreze 1992, Chen 2001]. Moreover, many sex workers in India are illiterate (47.8% in Bangalore to 82.0% in Belgaum in 2004-05 in this setting) (Table 1.1), as are 46% of women in India [Sharma 2001, Velkoff 1998].

According to the World Economic Forum, the average annual wage of women across India is US$1,185, or US$98.75 per month, while women's earnings via sex work in Karnataka averaged between US$80.53 to US$275.44 per month (Table 1.1). However, younger women (<25 years) in sex work in this setting can earn up to twice this amount. Sex workers in Karnataka also reported other sources of income from working in a variety of relatively low-paying professions, including labour (agricultural and non-agricultural), small businesses, maid servant professions and handicrafts (Table 1.1). The proportion of women who reported sex work as their sole income across the five districts in Karnataka in 2004-05 ranged from 20.9% in Shimoga to 55.2% in Mysore (Table 1.1).

The work environments of sex workers (e.g., homes, brothels, public places) in which FSWs solicit or service clients also appear to affect women's risk for contracting HIV and/or STIs. These also vary according to the local social and environmental context [Aral et al., 2006, Blanchard and Moses 2007, Buzdugan et al., 2009, Harcourt and Donovan 2005, Jana et al., 2006, Rekart 2005]. For example, local law enforcement practices influence the settings in which women solicit and service clients. In India, it is illegal to solicit clients for the purposes of prostitution and to own or operate brothels [2008 Human Rights Report, India 2008, Hindle et al., 2003]. Police 'crackdowns' can force those women to solicit clients in more deserted or isolated settings, where they may be at increased risk for violence and have poorer access to health resources and services. Fear of police also results in women not carrying condoms to avoid being identified as sex workers [Biradavolu et al., 2009, Hubbard 2004, Hubbard et al., 2008, Jayasree 2004, O'Brien 2009, O'Neil et al., 2004, Rhodes et al., 2008, Shannon et al., 2008a, Shannon et al., 2008b]. In some cases, aggressive policing policies have resulted in displacement of FSWs to other cities or towns [O'Neil et al., 2004]. While working in/operating brothels also is illegal, these indoor settings are often tacitly tolerated by local communities, including law enforcement agencies [Biradavolu et al., 2009]. While brothels may impede women's ability to choose their types and numbers of clients, they also have been shown to be settings where FSWs can more easily access prevention programmes and are more likely to use condoms [Buzdugan et al., 2009, Harcourt and Donovan 2005]. The distribution of the work environments of FSWs in Karnataka varied substantially according to local contexts and geographic setting and is constantly evolving. For example, in Mysore, the vast majority of women solicited primarily in public places (e.g., on the streets), while an approximately equal proportion of women solicited in homes, brothels and in public places in Belgaum (Table 1.1). Increasingly, women also are reporting using cell phones to contact their clients.

Globally, the predominant social perception of FSWs is negative; they are often portrayed as immoral and as 'vectors' of disease [Cornish 2006, Kempadoo 2009, Scambler and Paoli 2008]. On the whole, sex work is highly stigmatized in Indian society, although in some places, such as northern rural districts of Karnataka (e.g., Belgaum, Bagalkot, Bijapur, and Dharwad), there is some degree of acceptance of 'traditional' forms of sex work from the *Devadasi* tradition [Blanchard et al., 2005, Dandona et al., 2006, O'Neil et al., 2004]. For example, in a sample of FSWs from northern Karnataka, approximately 26% of FSWs began sex work through the *Devadasi* tradition. In the past, these women were responsible for performing various temple duties representing sacred forms of worship to religious deities (e.g., cleaning devotional items, dancing for deities in festivals, and delivering prayers and food to Gods) [Kersenboom 1987]. However, in the current form of the *Devadasi* tradition, girls (ages of 6-9 years) are dedicated to gods or goddesses and begin sex work shortly after their first menstruation. Their parents or other relatives, who frequently live in poverty, are paid compensation. Those working in the *Devadasi* tradition report accepting their role as economic providers for their families [O'Neil et al., 2004, Orchard 2007]. There is evidence to suggest that the profiles of risk for HIV and STIs for *Devadasi* sex workers compared to non-*Devadasi* sex workers may be different. *Devadasi* sex workers are more likely to work in rural areas, be illiterate, initiate sex work at a younger age and work out of their homes. However, they are also less likely to report client violence or police harassment and more likely to own their own homes [Blanchard et al., 2005].

Negative perceptions surrounding sex work, combined with reduced economic opportunities for women, have typically hindered the development of economic alternatives to sex work in India [Asthana and Oostvogels 1996, Evans and Lambert 1997]. In addition, few prevention programmes have successfully de-stigmatized sex work as a valid and practical occupation, taking into consideration that women often enter sex work due to limited other options. Recently, however, FSWs in India have begun to engage in collectivization processes, asserting their agency [Butcher and Welbourn 2008] and resisting previous intervention approaches that focused on reduction of sex work or exiting sex work. Using alternative techniques associated with collectivization, community engagement and empowerment of women in sex work, these novel approaches focus on the creation of "enabling environments" in which sex workers can more easily practice safer sex behaviour. Emerging evidence indicates that such approaches may have positive outcomes for sex workers, including the reduction of HIV and STIs and improvements in condom use [Jana et al., 2004, Jana et al., 2006, Sarkar 2010], though more rigorous evaluation of such programmes is needed. The proportion of FSWs in Karnataka who reported being part of a collective varied substantially across districts, ranging from 3.9% in Shimoga to 24.2% in Bellary in 2004-05 (Table 1.1). There appears to be a trend toward increased collectivization in several districts in Karnataka. For example, in 2007-08, the proportion of women reporting being part of a sex work collective was 22.6% in Shimoga and 27.8% in Bellary (Table 1.1).

Table 1.1: Characteristics of the study population: self-reports from female sex workers in Karnataka state, India.[1]

Factor	Bangalore				Belgaum				Bellary				Mysore				Shimoga			
	Round 1		Round 2[2]		Round 1		Round 2		Round 1		Round 2		Round 1[2]		Round 2		Round 1		Round 2	
	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N
Reason for getting into sex work																				
Widowed	11.8	79		n/a	11.4	42	19.7	79	13.8	58	10.3	46		n/a	14.4	61	12.4	51	25.7	101
Deserted by husband	21.4	125			11.0	46	23.4	94	12.5	67	16.6	72			26.8	120	10.1	45	24.5	99
Trafficked	1.9	10			7.1	28	1.0	4	4.7	23	2.5	11			15.3	52	11.1	45	0.5	2
Drug use	0	0			1.9	7	0.0	0	1.0	6	0.0	0			2.8	13	1.3	6	0.5	2
Wanted better life	80.7	557			87.5	334	79.4	319	79.1	330	88.7	362			17.0	76	84.3	326	87.0	350
Education																				
Illiterate	47.8	313	49.6	377	82.0	313	78.1	314	66.1	303	76.7	311	75.5	324	74.9	317	61.5	237	56.5	227
Literate	52.2	363	50.4	379	18.0	71	21.9	88	33.9	124	23.3	100	24.5	105	25.1	108	38.5	157	43.5	174
Amount charged per sexual encounter (rupees)[3](mean)		360.2		477.0		89.9		143.3		122.7		192.7		170.9		180.3		138.7		228.7
Monthly sex work income (rupees) (mean)		12,918.3		16,143.6		4,353.2		7,437.5		5,200.6		13,208.7		4,803.2		7,712.0		3,776.7		7,864.4
Sex work sole income																				
Yes	43.3	296	48.1	358	43.7	154	40.1	159	28.7	136	37.7	152	55.2	237	62.9	267	20.9	81	20.0	81
No	56.7	371	51.9	398	56.3	226	59.9	236	71.3	291	62.3	258	44.8	192	37.1	155	79.1	303	80.0	320

Factor	Bangalore				Belgaum				Bellary				Mysore				Shimoga			
	Round 1		Round 2[2]		Round 1		Round 2		Round 1		Round 2		Round 1[2]		Round 2		Round 1		Round 2	
	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N
Type paid work																				
None	43.4	296		n/a	43.7	154	40.1	159	28.7	136	37.7	152		n/a	62.9	267	20.9	81	20.0	81
Non-ag. Labour	13.0	93			17.8	62	20.3	80	21.4	97	18.9	76			5.7	24	19.5	68	14.7	58
Petty business	18.1	112			5.5	21	6.9	27	6.6	25	4.2	18			5.9	26	7.5	29	3.8	15
Maid servant	15.9	105			4.5	19	8.8	35	8.9	41	9.1	37			14.0	53	19.4	79	23.5	96
Ag. Labour	1.6	11			21.3	93	16.3	64	22.3	92	21.1	86			4.7	20	22.8	88	21.7	85
Handicrafts	3.4	24			1.1	5	1.8	7	0.4	2	2.4	11			2.3	11	1.3	4	1.4	6
Other	4.8	26			6.2	26	5.8	23	11.7	34	6.6	30			4.6	21	8.5	35	14.9	60
Work environment																				
Home	13.3	157	33.6	319	29.0	130	20.2	81	60.6	200	50.4	200	11.7	50	5.5	25	52.8	215	62.9	273
Brothel	3.6	48	7.3	73	33.6	97	24.5	102	7.0	43	15.4	69	0.5	2	3.8	16	5.2	22	0.2	1
Public	83.0	471	59.0	364	37.4	157	55.2	218	32.4	184	34.3	142	87.9	377	90.7	384	42.0	155	36.9	127
Member of collective	6.6	45	9.9	74	19.3	88	16.5	66	24.2	99	37.8	156		n/a	65.3	280	3.9	17	22.6	91

[1] Round 1 was conducted in 2004-05 while Round 2 was conducted in 2007-8.
[2] Some questions were not asked in Mysore round 1 and Bangalore round 2.
[3] At the time of writing this dissertation, one rupee was equal to 0.0213 $US.

1.4 THEORETICAL ORIENTATION

The current study is informed by theoretical models that acknowledge the importance of considering multiple levels of influence on risk behaviour and incorporate a gender-based approach (e.g., Risk Environment Framework [Gender Analysis in Health: A Review of Selected Tools 2002, Gender and Sex Based Analysis: Resource Guide n.d., Krieger 2003, Rhodes 2002]. These models are beginning to be applied in studies that aim to understand FSWs' risk environments and their vulnerability to HIV, highlighting the importance of explanations of HIV risk that are situated within social, economic, political and physical environments. This dissertation also draws on theoretical approaches that emphasize the importance of accounting for the heterogeneity of HIV epidemics. The transmission dynamics of HIV is conceptualized as being highly dependent on the behaviour of core groups and the sex partnering patterns between sub-groups. Core groups play an important role in spreading and maintaining the transmission of STIs and HIV in populations with both high and low rates of sex partners [Anderson and May 1991, Anderson 1999, Anderson and Garnett 2000, Thomas and Tucker 1996]. Core group theory will be described in more detail in Chapter 2 (Section 2.2). By integrating core group theory with ongoing theoretical and empirical work that amalgamates the importance of distal and proximate factors operating on multiple levels [Aral et al., 2007, Blanchard 2009, Diez Roux 2007, Poundstone et al., 2004, Rhodes 2002, Rhodes and Simic 2005], the current dissertation provides a detailed examination of how sexual structure in a population can be shaped by social and environmental factors, and how sexual structure can influence HIV infection rates and prevention.

1.5 RATIONALE FOR THE CURRENT STUDY

There are important gaps in knowledge regarding the features of sexual structure of FSWs and their male sex partners, and how sexual structure can be shaped by social and environmental factors in different contexts. One of the most important features of sexual behaviour relating to HIV transmission is the number of sexual partners that individuals have. It has been well-established that having many sex partners places individuals at higher risk for HIV [Msuya et al., 2006, Quigley et al., 1997, van den Hoek et al., 2001, Wang et al., 2007a], although condom use has been shown to be one of the most effective means of reducing the risk of HIV sexual transmission. Indeed, much previous research has focused on understanding how the sexual behaviour of FSWs (e.g., numbers of sex partners, condom use), combined with biological properties of the HIV virus and modes of its transmission (e.g., sexual versus injection drug use transmission), can place individuals at risk for acquiring and transmitting HIV. While the risk of infection can be influenced by other factors (e.g., condom use and the number of sex acts), a partnership must take place before protected and un-protected sex acts occur. Thus, the number of sex partners conveys important information on the raw potential of HIV transmission. Given the high numbers of sex partners that FSWs have (primarily commercial clients) and the lack of current information on factors associated with numbers of commercial partners of FSWs represents an important gap in knowledge. No studies that I am aware of have comprehensively investigated the social and environmental factors influencing the numbers of clients of FSWs.

Aggregate characteristics of FSW populations (e.g., average numbers of clients of FSWs, condom use and FSW population size) are frequently used to characterize HIV risk on a population level, as well as HIV transmission dynamics [Blanchard and Aral 2010]. These indicators can be useful and are relatively straightforward data to collect using surveys and mapping and enumeration methods, with the caveat that self-reported data is subject to social desirability bias and other methodological biases. However, these summary indicators can conceal substantial heterogeneity within FSW populations, which may be important in explaining differences in HIV prevalence across FSWs [Blanchard and Aral 2010]. Moreover, there may not be a linear relationship between these measures and HIV/STIs risk on an individual- or population-level [Parazzini et al., 1995 , Pequegnat et al., 2000], highlighting the importance of considering the complex interactions between individuals in a population that contribute to risk and emphasizing the limitations of relying *solely* on condom non-use or numbers of sex partners as markers of individual- or population-level risk for the acquisition or transmission of HIV/STIs. In previous studies, some factors that have been shown to influence the probability of sexual transmission of HIV have been studied in detail, including the presence of other STIs, type of sex act (e.g., anal versus vaginal) and the biological sex of the susceptible individual [Boily et al., 2009, Ward and Ronn 2010]. Features of the sexual structure of FSWs and their partners (other than numbers of sex partners and their relationships to HIV infection) have not been studied in detail, in India or in other settings. For example, little is known about the characteristics of different types of commercial partnerships (e.g., repeat versus occasional clients) and sex partnering patterns on a population level. While previous studies also have described some important details regarding patterns of sexual contacts of FSWs and hypothesized how these can influence HIV or STI infection rates, additional studies that are grounded in local contexts and use site-specific data are required [Aral and St. Lawrence 2002, Aral et al., 2006, Blanchard et al., 2008b, Blanchard and Aral 2010, Ghani and Aral 2005].

Given the high HIV prevalence rates among FSWs in southern India (Figure 1.2) and the ongoing vulnerability faced by FSWs to HIV infection, gaining a more comprehensive understanding of how sexual structure operates within local contexts in southern India to create risk environments for HIV transmission is crucial for informing the continued development of HIV interventions in these areas. Substantial heterogeneity exists within and across geographic regions in India both in terms of HIV prevalence and sexual structure of FSWs and their male partners (i.e., numbers and distributions of FSWs; sexual partnering patterns; numbers of clients of FSWs) [Blanchard et al., 2007]. However, there is an overall paucity of knowledge that assesses how heterogeneity in the sexual structure of a population can influence HIV infection rates and even less is known within FSW populations, including those residing in southern India.

Moreover, little is known regarding the effectiveness of the Avahan AIDS Initiative, the largest ongoing core group intervention in southern India, in terms of increasing condom use within different types of partnerships of FSWs and populations with different sexual structures. Previous studies suggest that condom use among FSWs has increased and STI prevalence has decreased over two years of survey data collection (2004-05 to 2007-08) [Ramesh et al., 2010, Reza-Paul et al., 2008]. These studies have focused on commercial sex partnerships of FSWs and address limited aspects of intervention exposure. Ongoing monitoring and evaluation of the Avahan AIDS Initiative has shown that observed declines in FSW HIV prevalence in different settings in southern India are consistent with empirical self-reported increases in condom use by commercial clients of FSWs following the Avahan AIDS Initiative [Lowndes et al., 2010, Pickles et al., 2010, Ramesh et al., 2010]. However, additional research is required to understand the effectiveness of this intervention within different types of sex partnerships (e.g., FSWs' intimate partnerships; FSWs' commercial partnerships). As well, further research could illuminate how the Avahan AIDS Initiative functions in local contexts that exhibit different sexual structures.

1.6 STUDY OBJECTIVES

The primary objective of this study was to describe the heterogeneity in sexual structure[4] of FSWs and their sex partners in southern India and the extent to which the heterogeneity in sexual structure influences HIV infection rates, and implications for prevention. The following three specific objectives are addressed and presented in Chapters 3 to 5.

1. The objective of Chapter 3 was to explore the geographic heterogeneity in the numbers of commercial sex clients of FSWs across five districts in Karnataka state. This analysis also investigated the strength of the association between social and environmental factors and the numbers of clients of FSWs, and compare observed patterns and associations geographically. The findings from this analysis informed the development of a mathematical model used to examine the impact of sexual structure on HIV prevalence.

2. The objective of Chapter 4 was to describe the heterogeneity in the sexual structure of FSWs and their male sex partners within and across three districts in Karnataka state. Using mathematical modelling techniques, this analysis also demonstrated how heterogeneity in sexual structure influenced HIV prevalence within and across districts. This analysis identified specific individual parameters that were important in explaining the differences in HIV prevalence between the three districts. Sexual structure parameters of interest within districts included measures of variability in the numbers of clients of FSWs, and within and

[4] In this dissertation, variability or heterogeneity in 'sexual structure' refers to the variability or heterogeneity in the numbers and types of sex partners and sex partnering patterns between female sex workers and their sex partners. This variability can be present both within districts (according to social and environmental factors or resulting from measures of variability in the distributions of the numbers of clients of FSWs) and across districts (on a population-level).

across districts included the numbers of clients of FSWs and numbers of visits to FSWs by clients, the frequency of sex acts with repeat and occasional clients, the fraction of repeat clients and repeat FSWs, the duration of the repeat client and repeat FSW relationship, FSW population size, and condom use with different sex partners.

3. The objective of Chapter 5 was to investigate the impact of exposure to the Avahan AIDS Initiative on condom use as reported by FSWs by their male sex partners in three districts in Karnataka state. Specifically, this analysis assessed if intervention exposure was associated with condom use by clients, including occasional clients and repeat clients, as well as condom use by non-paying partners and husbands/cohabiting partners[5].

The analyses in the current dissertation are based on data gathered through two primary data collection efforts: (1) the IBBA; and (2) the Special Behavioural Surveys (SBS). The primary data were collected in five districts in Karnataka state (Bangalore, Belgaum, Bellary, Mysore and Shimoga districts) as part of the Avahan AIDS Initiative [Avahan, the India AIDS Initiative - the Business of HIV prevention at Scale 2008]. The IBBA was implemented by the Karnataka Health Promotion Trust (KHPT), Bangalore, India in collaboration with the University of Manitoba, Winnipeg, Canada. The SBS was implemented by the CHARME-India project in collaboration with the Institute of Population Health and Clinical Research, St John's Medical College, Bangalore and the Centre hospitalier *afflilié* universitaire de Québec, Quebec, Canada. Both surveys collected information on socio-demographics, sexual risk behaviour and sex work environment. Biological samples (HIV and STIs) were collected via the IBBA. Several

[5] Non-paying partners and husbands/cohabiting partners collectively encompass 'intimate' or 'non-commercial' partners. These terms will be used interchangeably throughout this dissertation.

types of probability-based cluster sampling designs were used to construct samples of FSWs in each district. Sampling weights were attached to individuals in each cluster [Ramesh et al., 2008]. The target sample size in Bangalore district was fixed at 800 to capture the different sex work typologies existing in larger cities, and the sample size in each of the other districts was fixed at 400. Details on the sampling method for the IBBA can be found in Ramesh et al 2008 [Ramesh et al., 2008]; similar methods were used for the SBS. The IBBA was conducted twice in most settings (2004-05 and 2007-08), although data collection for a third round is ongoing. The SBS was conducted once in 2005-06 only. Both surveys were administered face-to-face by trained interviewers in the local language (*Kannada*) and were conducted anonymously, with no names or personal identifiers recorded. The surveys and their protocols were approved by the Government of India's Health Ministry Screening Committee and the respective Canadian university research ethics boards.

1.7 OVERVIEW OF THE DISSERTATION

The current dissertation takes a multi-phased analytic approach to empirically address the three research objectives described above, comprising the material presented in Chapters 3, 4 and 5. Two additional chapters are included in addition to the Introduction (Chapter 1). Chapter 2 provides a synthesis of the emerging research literature regarding important features of sexual structure and their relationships to individual (Section 2.1) and population-level (Section 2.2) HIV risk, as well implications for interventions to reduce HIV rates in southern India (Section 2.3). Chapter 6 provides a summary of the discussion of the findings from the three analyses described in Chapters 3-5, and describes potential implications of the current research.

CHAPTER 2

LITERATURE REVIEW

2.1 SEXUAL STRUCTURE AND PUTATIVE LINKS TO INDIVIDUAL HIV RISK

The importance of numbers of sex partners as a marker for HIV risk

An important feature relating to sexual structure is an individual's numbers of sex partners. Many studies have found that having greater numbers of partners is associated with higher HIV prevalence [Msuya et al., 2006, Quigley et al., 1997, van den Hoek et al., 2001, Wang et al., 2007a], including female sex workers (FSWs) from six states in India[6] [Ramesh et al., 2008]. The majority of FSWs' sex partners are commercial sex clients, either occasional clients or repeat clients. FSWs in southern India report hundreds of new clients per year [Deering et al., 2010b] compared to women in the general Indian population, where under 1% report having more than one lifetime sex partner [Munro et al., 2008]. Women with more clients have a higher risk of being exposed to HIV/STIs as well as other health risks, including physical violence and sexual assault [Beattie et al., 2010]. Although the average probability of male-to-female transmission of HIV per sex act in resource-constrained or developing country settings is estimated to be low, at about 0.1%-0.6% per sex act[7] [Boily et al., 2009], high rates of partner change amongst FSWs sustained over time can result in high lifetime risk for becoming HIV

[6] The minority of studies have found that fewer numbers of sex partners are associated with HIV prevalence (van den Hoek et al 2001; Vandepitte et al. 2007). It is likely that the latter results were found because of the cross-sectional nature of the studies, since individuals with HIV may reduce sex partner volume due to illness, or have current sexual behaviour that does not reflect the sexual behaviour they had when infected.

[7] There are a variety of individual-level co-factors that also influence risk of acquisition and transmission of infection for each sex partner, including the type of sex act (e.g., anal, vaginal, oral), the number of sex acts (e.g., repeated sex acts versus one sex act in one partnership) with an infected individual, the infection status of an partner, use of protective measures (e.g., condoms), and timing of the sexual contact (e.g., at what stage of infection is the infected partner) (Boily et al., 2009; O'Byrne et al. 2008; Nordvik and Liljeros 2006).

positive. HIV/STI prevention interventions also frequently focus services on women with more clients [Hogle et al., 2002, Sarkar 2010, Shelton et al., 2004]. Information that characterizes the factors associated with higher numbers of clients therefore can also inform intervention design[8].

Epidemiological and methodological features of distributions of sex partners

Modelling of the numbers of sex partners on an individual level requires some discussion of the distribution of the numbers of sex partners across a population. Moreover, the underlying behavioural processes that generate different distributions can provide important insights into HIV risk on an individual and population level. Section 2.2 describes additional features of distributions of the numbers of sex partners (e.g., variance) that influence HIV risk on a population level. Much of the research on distributions of numbers of sex partners has been done within general populations rather than focused in core groups such as FSWs. However, some of this research remains applicable to FSW populations.

Distributions of sex partners in general populations have been found to be highly right-skewed, with a long upper tail, which means that most individuals have few sex partners and few have many [Brisson et al., 1999, Hamilton et al., 2008]. FSW populations in India and Pakistan have also been shown to follow this pattern [Blanchard et al., 2007, Blanchard et al., 2008b]. Information from other settings is limited. Various statistical distributions (e.g., the Poisson, gamma and negative binomial), have been used to characterize this pattern in general populations

[8] There are limitations to the use of numbers of sex partners as a sole marker of HIV vulnerability (Pinkerton et al. 2003), since individuals with high numbers of sex partners may be reticent about reporting their numbers of partners. Individuals who fall outside of a specific (and sometimes arbitrary) definition of high risk may not be encouraged to get tested for HIV by healthcare providers, despite having other characteristics that place them at high risk for infection (O'Byrne et al 2008). FSWs also may avoid testing and treatment due to fears of stigmatization (Day and Ward, 1997).

and to model the numbers of sex partners on an individual level [Brisson et al., 1999, Hamilton et al., 2008, Nagelkerke et al., 2006]. These distributions are assumed to be generated by underlying behaviour processes that define partnership acquisition.

The Poisson distribution is generated through a behaviour process that occurs at a fixed homogenous rate over time. This behaviour process is not thought to be realistic, since everyone in the population is assumed to have the same propensity to form sexual relationships [Hamilton et al., 2008]. The negative binomial distribution is generated by a partnership formation process that occurs via a search process with a stopping rule. In other words, partners are acquired with a probability *p* until the search is stopped when $r=m$ suitable partners are found (i.e., desired numbers of partners). The geometric distribution is generated when the search stops with only one partner (i.e., $r=1$) [Hamilton et al., 2008, Handcock and Jones 2004]. A two-stage vetting process can generate the negative binomial Yule, geometric Yule and discrete Pareto exponential distributions [Hamilton et al., 2008, Handcock and Jones 2004]. In other words, individuals develop a list of acquaintances whom they would consider as sex partners (first stage of the vetting process). The inclusion of a potential partner in the list may depend on whether or not he/she is included in an individual's social network or geographic region. Then, individuals choose their sex partners from this acquaintance list (second stage of the vetting process). Moreover, this may depend on whether or not the sex partner satisfies some independent criteria (e.g., sex, age, marital status, gender) [Hamilton et al., 2008]. A behavioural process termed 'preferential attachment', whereby individuals with more partners are more likely to be chosen as a partner and the population does not have a finite size, can generate a power law distribution with scaling exponent *p* ($2 < p \leq 3$) [Hamilton et al., 2008, O'Byrne et al., 2008, Schneeberger et al., 2004]. One feature of a power law distribution with a scaling exponent in this range is that

R_0 (a threshold parameter) is necessarily >1 since the variance is infinite (see Equation 2.2 in Section 2.2), an observation that was made in early mathematical modeling studies [Anderson and May 1991, Diekmann et al., 1990, May and Lloyd 2001]). In that case, there is a high probability of an epidemic, even for pathogens like HIV, which have low transmissibility [May and Lloyd 2001].

Hamilton et al (2008) found that the negative binomial distribution best fit the distributions of the numbers of sex partners in five different general population surveys in the United States. Authors then argued that the behavioural process that generated the negative binomial distribution also represented the most appropriate behavioural process to the US population [Hamilton et al., 2008]. In southern India, however, it remains unclear as to which behavioural process model generates the distribution of the numbers of clients of FSWs. More than one model seems to be able to describe the essentials of the behavioural process. For example, partner acquisition of FSWs in southern India may be generated by a preferential attachment model (e.g., where FSWs with more clients are also more likely themselves to be chosen as a partner), or a search-and-stop rule of acquiring sex partners (e.g., if FSWs acquire only enough partners to satisfy a desired level of income). Methodologically, the shape of the distribution of the numbers of clients of FSWs is important when choosing a regression model because an incorrectly specified model can influence regression coefficients or standard errors and produce misleading results [Cameron and Trivedi 1998, Xu et al., 2008]. Although it is likely that the distribution of the numbers of commercial partners in southern India can be modeled using several of the above distributions (e.g., negative binomial, gamma) without large differences in epidemiological patterning, the negative binomial distribution in particular is often found to be well-suited to account for the overdispersed nature of sex partner distributions. The analysis in Chapter 3 used a negative binomial model and accounts for these methodological and epidemiological considerations.

Social and environmental factors influencing numbers of sex partners

To better identify which individuals are at higher risk for becoming HIV-positive, previous research has focused on describing which social and environmental factors (e.g., marital status; education; geographic place of residence) are associated with sexual behaviour such as condom use. Far fewer attempt to describe the distal social and environmental determinants of numbers of sexual partners. Those that do so frequently examine bivariate associations only, or use population-based surveys of sexual behaviour in high-income countries [Brisson et al., 1999, Nagelkerke et al., 2006, Novak and Karlsson 2006]; moreover, none have done so for FSW populations[9].

The numbers of sex partners of FSWs may be influenced by a variety of social and environmental factors. For example, geographic region or place of residence may influence FSWs' numbers of clients, as was the case with Kenyan sex workers in urban Nairobi townships who reported having significantly higher numbers of clients and charged more per sexual encounter compared to women in rural towns [Elmore-Meegan et al., 2004]. The relative amount of money that women make per sex act may also influence their numbers of partners [Harcourt and Donovan 2005, Minh et al., 2004]. Women who make less money per encounter may require more clients to achieve a target income, whereas women who are able to charge high prices (e.g., young women) may have more clients in order to maximize their earnings over shorter periods of

[9] One of the reasons for this is likely due to the challenges of accurately estimating the numbers of sex partners of FSWs. To address this challenge, numbers of sex partners are sometimes collected in categories rather than continuously. However, a continuous, rather than categorical variable is required to characterize the heterogeneity in rates of sex partners more precisely.

time (e.g., during festivals). Younger women tend to have more clients than older women [Sarkar et al., 2006, Sarkar et al., 2008]. Cultural contexts of the working environment of sex workers influence FSWs' numbers of clients [Vandepitte et al., 2007]. For example, in northern Karnataka, FSWs from the *Devadasi* tradition reported having higher numbers of clients and lower average amounts charged per sexual encounter compared to non-*Devadasi* FSWs [Blanchard et al., 2005]. It is also hypothesized that in some parts of southern India, young women who have been in sex work for a short duration, and who also work in brothels, may have a high share of the total volume of clients [Blanchard 2009]. Women who work in brothels may require more clients to earn sufficient money to pay their pimps, madams or brothel owners [Buzdugan et al., 2009]. The numbers of clients that FSWs have may also depend on their marital status. For example, since some married women practice sex work without their husbands' knowledge, they may only be able to entertain clients during limited hours (e.g., while their husbands are away at work). Unmarried FSWs are likely to depend exclusively on sex work for their incomes in Karnataka [Ramesh et al., 2008], suggesting that these women may have higher numbers of clients.

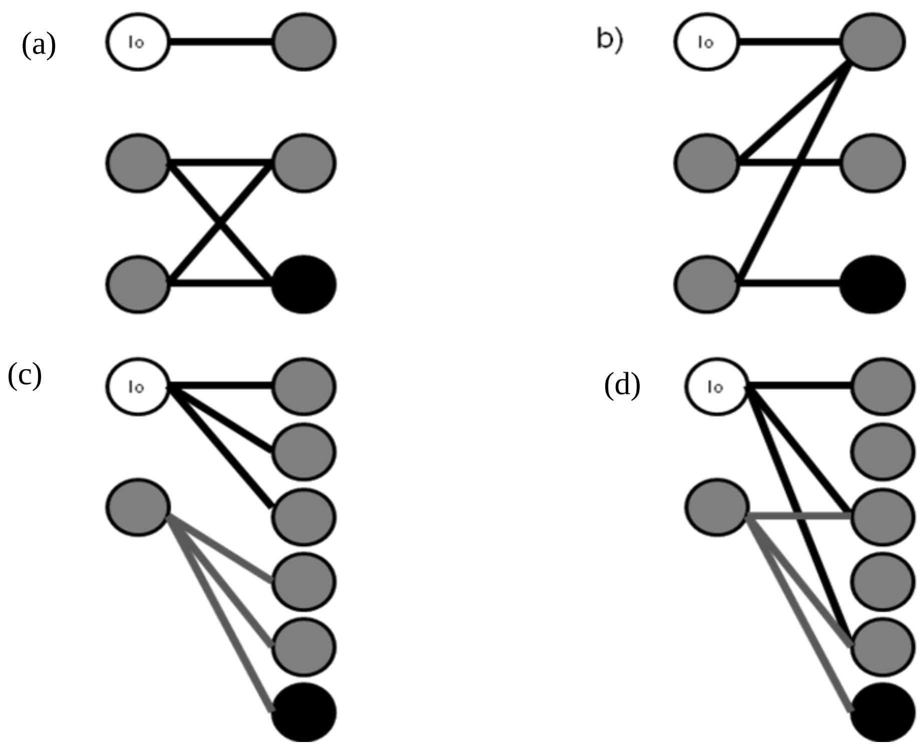
Sex partnering patterns and individual HIV risk

Along with the *numbers* of sex partners, an individual's *patterns* of sexual contacts, as well as their partners' sexual *behaviours* (e.g., number of sex partners; condom use) are important for determining an individual's risk of being infected with HIV, as well as transmitting it [Ward 2007]. For example, consider an individual (Io) with only one sex partner with whom she engages in multiple sexual acts. If she is her partner's only partner, and neither of them is HIV positive, she will never acquire HIV (Figure 2.1a). However, if her partner has multiple partners, each of whom has multiple partners, the probability that she will be exposed to HIV and become HIV positive is much higher [Ward 2007] (Figure 2.1b). However, if Io is a FSW, her high numbers of commercial sex clients places her at higher risk of becoming HIV positive, assuming there is some probability of her coming into contact with an infected individual. The sexual behaviours of Io's clients, including any other sex partners is also important. If Io is each of her clients' only sex partner, then the probability of her being exposed to HIV is likely minimal (Figure 2.1c). However, if there is overlap in terms of her clients' commercial sex partners then the probability of infection may be increased (Figure 2.1d).

Few studies that examine such patterns of sexual contact in detail have been conducted, particularly in high-risk and hidden populations such as FSWs. Such studies can be costly, labour-intensive, as well as ethically and practically challenging to implement since study participants are often asked to convince their sex partners to also participate in the study and reveal *their* sexual behaviour [Day et al., 1998, Klovdahl 2005]. There are also methodological challenges associated with data collection procedures, whereby the sample will likely be biased by non-independence of observations and missing data [Boily et al., 2000, Boily et al., 2007a, Ghani et al., 1997]. Thus, particularly for individuals with high rates of partner change (e.g., FSWs), sex partnering patterns are most usually characterized using egocentric data (e.g., information on sex partners that is reported by proxy by FSWs). While subject to bias, these data are feasible to gather and are thought to provide the best possible estimates of sex partners' behaviours under the circumstances.

However, little attention has been paid to descriptions of patterns of sexual contact between FSWs and their sex partners (e.g., numbers of sex acts; numbers of different types of partners), which also may influence FSWs' risk for HIV infection, outside of studies that have observed different levels of condom use within different types of sex partnerships of FSWs. Condom use decreases within longer-term or more intimate sexual partnerships, including in relationships with FSWs [Barrientos et al., 2007, Chan and Man 2002, Figueroa et al., 2007, Gorbach et al., 2006, Luke 2006, Murray et al., 2007, Voeten et al., 2007, Wang et al., 2007a]. As well, within commercial sex partnerships of FSWs, reported condom use is usually higher with occasional compared with repeat clients [Hanck et al., 2008, Malta et al., 2008, Reza-Paul et al., 2008].

Figure 2.1: The structure of the sexual network of (Io) and her sex partners. The average numbers of sex partners of Io and the entire population (including Io) in (a) and (b) are the same (1 and 1.7 respectively). The average numbers of sex partners of Io and the population are also the same in (c) and (d) (3 and 2 respectively).[1]



[1]This figure was inspired by and adapted from Ward et al. 2007. White circles represent the uninfected individual of interest (I_0). Grey circles represent others in the population who are HIV-negative. Black circles represent others in the population who are HIV-positive. Lines denote sexual partnerships between individuals in the population.

2.2 SEXUAL STRUCTURE AND HIV EPIDEMICS

The importance of heterogeneity in the numbers of sex partners to HIV epidemics

At an *individual* level, the number of different sex partners that an individual has appears to be an important predictor of being exposed to an HIV-positive partner and/or becoming infected with HIV, as was described in more detail in Section 2.1. Each sex act with an HIV-positive sex partner presents an opportunity for transmission of infection. The average numbers of sex partners (lifetime or new partners per unit time) also may play an important role in *population-level* HIV prevalence [Anderson 1999, Blanchard and Aral 2010, Cassels et al., 2008, Chen et al., 2007, Garnett et al., 2008, O'Byrne et al., 2008]. However, some studies have suggested that assuming a homogenous sex partner contact rate across an entire population can be an oversimplified approach to understanding the relationship between numbers of sex partners and HIV risk on a population level, particularly among FSWs [Blanchard et al., 2007, Blanchard et al., 2008b].

Moreover, increased heterogeneity in the numbers of sex partners can increase the likelihood of an epidemic [Anderson and May 1991, Boily 2009]. Important concepts from mathematical modeling have played an important role in understanding the influence of numbers of sexual partners on HIV and STI transmission dynamics [Anderson and May 1991, Garnett 2002, Mishra et al., 2011]. Previous research has identified the importance of variability in the numbers of sex partners using R_0, the basic reproductive ratio [Anderson and May 1991, Diekmann et al., 1990]. Equation 2.1 represents key components of transmission of any infectious disease in a population, under the assumption that the density of susceptible individuals in a population does not decrease due to the infection process (i.e., in an entirely susceptible population). In its simplest form R_0 is defined as:

$$R_0 = \beta c \delta \qquad \text{(Equation 2.1)}$$

Where β represents the transmissibility of infection, *c* represents the average contact rate (average numbers of new sex partners per unit time) and δ represents the duration of infectiousness (Anderson and May 1991). If $\boldsymbol{R_0} \leq 1$, an initial typical infected individual introduced into a wholly susceptible population will likely produce no additional infections during his/her entire infectious period and the epidemic will die out. If $\boldsymbol{R_0} \geq 1$, the initial infected individual will likely produce at least one other infection during his/her entire infectious period and the epidemic will likely continue [Anderson and May 1991]. Notably, Equation 2.1 describes a simplified representation of the sexual behaviour of a population because it assumes a homogeneous contact rate with sex partners across the entire population, denoted as "*c*" [Anderson and May 1991]. Researchers have adopted a more realistic approach, which allows for heterogeneity in contact rates. Such heterogeneity is represented by Equation 2.2, where *c* represents the average contact rate and the heterogeneity in contact rates within the population is captured by the variance, σ^2 [Anderson and May 1991, Diekmann et al., 1990, Hyman and Li 2000]. Thus, as σ^2 increases, the heterogeneity in the distribution of the numbers of new sexual partners increases, and the likelihood of an epidemic, indicated by R_0 also increases.

$$R_0 = \beta(c + \sigma^2/c)\delta \qquad \text{(Equation 2.2[10])}$$

[10] This assumption is only valid under the assumption of proportionate mixing, which is discussed in the following Section: "**Sex partnering patterns and HIV epidemics".**

Core group theory and heterogeneity in rates of sex partners

The observation that heterogeneity in the number of sexual contacts in a population is critical to the establishment and persistence of HIV epidemics has developed in tandem with the concept of the 'core group'. The core group is defined as a "set of individuals who have a level of risk behaviour sufficient to generate viable chains of transmission in a population and in absence of which the infection would die out" [Boily et al., 2002, page i78]. The concept of a core group was first described by Yorke et al. (1978) to help explain the low, but stable prevalence of gonorrhoea in the USA, despite the fact that the disease had no acquired immunity. Yorke et al. (1978) suggested that a density-dependent mechanism may be at work, indicating that pre-emptive[11] saturation may be taking effect [Yorke et al., 1978]. Since the general population had low gonorrhoea prevalence, this mechanism was more likely to be occurring in a smaller group of individuals with high contact and re-infection rates, a 'core group' [Cassels et al., 2008, Ward 2007, Yorke et al., 1978]. Subsequently, mathematical models demonstrated that even if the general population had a low average rate of sexual contacts, the presence of a small group of individuals with high numbers of sexual contacts could sustain the epidemic [Anderson and May 1991, Anderson et al., 1991, Yorke et al., 1978]. The findings of these early studies suggested that interventions targeted toward core groups could have a significant impact on HIV epidemics [Anderson and May 1991]; thus, identifying core groups is thought to be critical to the success of HIV prevention interventions in many settings. Examples of core group interventions are discussed in Section 2.3 of this chapter.

However, identifying core groups has proven to be difficult to operationalize in practice. The definition of a core group has varied across different STIs; for bacterial STIs (e.g.,

[11] For example, onward transmission is limited due to contact with already infected individuals.

gonorrhoea and Chlamydia), where infections can be treated and resolved, the core group has been defined as individuals who are infected a large proportion of the time, infect more than one other person, or are repeatedly infected [Brunham 1991, Thomas and Tucker 1996]. However, these definitions do not apply to viral infections (e.g., HIV), which cannot be cured or resolved naturally. Although theoretically, core groups are those that would sustain the infection in a population, in practice the definitions are less concrete. Researchers have attempted to characterize core groups based on individuals' risk behaviour and it is assumed that infections in these individuals are more likely to transmit infections more than the average individual in a population. Often, individuals with high numbers of sex partners are classified as a core group [Thomas and Tucker 1996]. Recent research has also suggested that small groups of individuals who sustain medium-length partnerships and who experience short gap lengths between successive partnerships may actually be those who sustain gonorrhoea infection in the United Kingdom, instead of individuals with high numbers of sex partners but longer gaps between partnerships [Chen et al., 2008]. This is based on mathematical modelling results whereby the assortative (like with like) mixing of individuals with short gaps between partnerships was required for gonorrhoea infection to persist. Moreover, interventions that were directed at individuals with shorter partnerships, but longer gaps between partnerships (i.e., those with the highest number of sex partners), were less effective than interventions targeted at individuals with medium-length partnerships (i.e., those with fewer partners) [Chen et al., 2008].

Sex workers have traditionally been classified as a core group, particularly in regions where HIV is primarily sexually transmitted, because of their higher rates of partner change relative to the general population [D'Costa et al., 1985, Moses et al., 1991, Potterat et al., 1979]. Commercial sex partnerships have been identified as playing a significant role in sustaining HIV transmission in the general population, including in southern India [Lowndes et al., 2002, Lowndes et al., 2008, Vickerman et al., 2010]. Building on these studies, as well as observations regarding the high variability in HIV prevalence and numbers of sex partners within FSWs populations, recent studies have suggested that it may be useful to reconceptualise and consider the impacts of 'cores within cores'. In other words, there likely exist very high-risk groups of sex workers who may play a significant role in driving and sustaining epidemics within FSW and client populations, which may ultimately influence HIV rates among general populations [Blanchard 2009].

Sex partnering patterns and HIV epidemics

Simple mathematical models initially assumed that individuals selected their sex partners at random. This means that every individual would have the same likelihood of being chosen, regardless of their social, behavioural or environmental characteristics, including their volume of sex partners. The degree of heterogeneity in their sexual activity was not taken into account [Anderson 1999, Garnett and Anderson 1996]. Models with increasing levels of complexity were subsequently developed by dividing the population into sub-groups of individuals with specific characteristics (e.g., according to differences in sexual behaviour such as average numbers of sex partners) who could choose their partner preferentially [Anderson et al., 1991, Anderson and Garnett 2000, Boily and Anderson 1991, Cassels et al., 2008, Garnett and Anderson 1996]. Sex partnering or mixing patterns between groups of individuals in a population were defined by population-level descriptions of who partners with whom (i.e., the fraction of individuals with a specific type of partner, such as commercial or non-commercial).

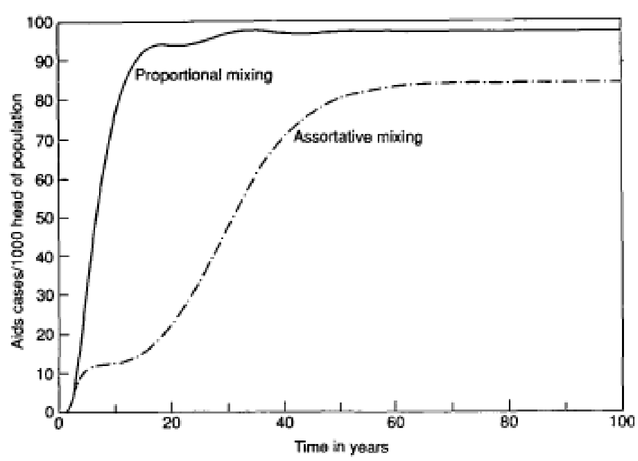
Sexual mixing patterns vary from purely assortative mixing (i.e., "like-with-like"), where only individuals with similar characteristics form sex partnerships with each other, to purely disassortative mixing, where individuals with only dissimilar characteristics form sex partnerships with each other [Boily and Masse 1997, Gupta et al., 1989]. Proportionate mixing lies between these two extremes, and occurs when there is no preference. In proportionate mixing, individuals mix randomly according to the availability of the number of partnerships in various populations [Boily and Masse 1997]. Models have demonstrated that the type of sexual mixing can have a substantial impact on the transmission dynamics of HIV infection on a population level. In populations with commercial sex partnerships and assortative mixing, FSWs and clients only have sex partnerships with each other. In this case, epidemics are thought to remain concentrated within these groups, resulting in a lower overall population prevalence of infection [Boily and Anderson 1991]. However, when FSWs and clients have sexual relationships with different partners (e.g., clients have both shorter-term FSW partners and longer-term wives), this can reflect increased proportionate mixing or disassortivity. In this case, the infection can spread to a wider population, resulting in a high overall prevalence of infection. Figure 2.2 demonstrates how the type of sexual mixing in a model assumed can influence the HIV epidemic over time.

Patterns of sexual contact between FSWs and clients can also influence HIV transmission in high-risk groups and general populations in other ways. This can be due to characteristics that define various types of sex partnerships, such as the numbers of sex acts or condom use. For example, FSWs have fewer sex acts with occasional clients than with repeat clients. An individual-based modelling study by Ghani and Aral (2005) found that STIs (with either short or long infectious periods) were more likely to persist and have a higher equilibrium prevalence when clients visited many different FSWs (e.g., occasional partnerships, with one sex act) compared to if they visited the same FSWs (i.e., repeat partnerships, with many sex acts per partnership) [Ghani and Aral 2005]. The number of sex partnerships between FSWs and clients (and numbers of clients per FSW) were assumed to remain the same in each scenario and condom use was not accounted for in this model, while the level of disassortivity increased when clients visited many different FSWs.

The relative contribution of the types of sex partnerships to HIV epidemics has been estimated in previous modelling studies in order to provide insights into epidemic dynamics and suggest where to focus interventions [Arora et al., 2004, Côté et al., 2004, Cowan et al., 2005, Gray 2001]. Results from a mathematical modelling study of HIV in rural Uganda suggested that the majority of incident HIV infections among men and women were attributed to occasional partnerships (e.g., FSWs, clients) early in the epidemic (1980). By 1994, when the epidemic matured, less than a quarter were attributed to occasional partnerships [Robinson et al., 1999]. In Karnataka state, modelling indicated that among all men, most annual incident HIV infections (>90%) since the start of the epidemic were due to commercial sex partnerships, with the remainder due to non-commercial partnerships with FSWs [Vickerman et al., 2010]. Among all women, most annual incident HIV infections (80%-90%) were due to non-commercial partnerships with men who were clients of FSWs, while the remainder were due to commercial sex (10%-20%) [Vickerman et al., 2010].

The sexual *networks* of populations have been proposed to help explain risk for acquisition and transmission of HIV/STIs [O'Byrne et al., 2008, Ward 2007]. Sexual network studies collect information on ‘nodes’ (individuals) and links between nodes (sexual relationships). Sexual networks describe an overall view on the structural links between individuals from different sexual activity groups and the possible paths of transmission and acquisition of infection [Newman et al., 2006, Ward 2007]. The utility of core group interventions has been questioned because these may overlook individuals who play an important role in the spread of disease through sexual networks (e.g., individuals who connect otherwise closed networks; individuals with multiple sex acts per partnership) [Ward 2007]. The identification of 'risk networks' specific to a disease and population has been proposed to potentially help direct novel intervention strategies in some settings [Ward 2007]. However, the lack of availability of sexual network data, and the particular challenges of collecting such data among FSWs (who may have hundreds of occasional sexual partners per year) limit the usefulness of this approach to understanding transmission dynamics in FSW populations. Nevertheless, insights from studies on sexual mixing patterns and sexual networks highlight the importance of measuring not only numbers of sex partners of FSWs and their male partners, but also the sex partnering patterns (e.g., occasional versus longer-term partnerships).

Figure 2.2: Predicted changes in the number of AIDS cases per 1000 head of the sexually active population for the case of proportional and strong assortative mixing (Reprinted with permission from Boily and Anderson, 1991 [Boily and Anderson 1991]).[1]



[1]Assortative mixing can help the establishment or minimize the spread of infection relative to proportionate mixing, depending on the value of R_0.

The role of mathematical modelling to understand HIV epidemics on a population level

Transmission dynamics mathematical models typically represent the spread of infections over time, space or age [Anderson and May 1991, Boily and Masse 1997]. In terms of HIV and STI epidemiology, such models are analytical tools that have been used primarily to understand the influence of social, biological and behavioural factors on how infectious diseases are acquired and transmitted on a population level, as well as to understand how the course of an infection progresses on an individual level [Garnett and Anderson 1996, Garnett 2002]. Some of the earliest applications of mathematical models of STI transmission on a population level were presented in two publications by Hethcote and Yorke that described models of gonorrhoea transmission (discussed earlier in Section 2.2) [Hethcote and Yorke 1984, Yorke et al., 1978]. This work was significant because of its use of theory as well as empirical data and because it aimed to make the work applicable to health care practice [Anderson 1999]. Several important concepts were introduced that continue to be used extensively today to promote an understanding of the transmission dynamics of HIV/STIs, including the basic reproductive ratio (R_0) and the core group [Anderson 1999].

Early mathematical models of STI transmission made simple assumptions of homogeneity of sexual behaviour in a population (as described earlier in this Section). Given observations that the risk of acquiring and transmitting infections can vary substantially across individuals in a population, more recent models have incorporated increased complexity to account for this heterogeneity (e.g., in terms of sexual behaviour, sex partnering patterns, stage of infection, biological sex, self-identified gender) [Anderson 1999, Mishra et al., 2011]. Since a model is by definition a simplification of reality, a balance must be struck between creating a model that is complex enough to accurately estimate and represent the characteristics of a population and the dynamics of acquisition and transmission of infection. These aspects of modeling need to be balanced against maintaining sufficient simplicity to permit researchers and policy-makers to effectively interpret and communicate results about the likely course of an epidemic and to recommend realistic actions for controlling the spread of disease [Anderson and Garnett 2000, Boily and Masse 1997, Garnett 2002, Ghani and Boily 2003].

Mathematical models can help identify important epidemiological parameters that influence the spread of infection. They also help to test epidemiological hypotheses and provide valuable evidence for intervention-related decisions as well as future studies (e.g., on which parameters should information be collected) [Boily and Masse 1997, Garnett 2002, Mishra et al., 2011]. In particular, conducting comprehensive sensitivity or uncertainty analyses can provide important insights to this respect [Mishra et al., 2011]. A sensitivity analysis is an assessment of the impact of certain epidemiological parameters of interest (e.g., sexual structure parameters) on model outcomes over a range of values [Mishra et al., 2011]. A sensitivity analysis can help evaluate changes in conditions that define an epidemic in specific settings (e.g., exchanging epidemiological parameters from one setting to another to determine important parameters describing differences in epidemics) [Mishra et al., 2011]. A one-way (i.e., varying one parameter while holding all others constant) or multivariable (i.e., varying one parameter at different values for another parameter) sensitivity analysis can be conducted [Mishra et al., 2011]. However, it is important to keep in mind that some variables in a model may be correlated; thus, a true one-way analysis is not actually being conducted. An uncertainty analysis is a type of sensitivity analysis that uses a narrower parameter range, usually chosen to describe a more realistic range for the parameters studied (e.g., 95% confidence intervals) [Mishra et al., 2011]. The aim of an uncertainty analysis, which is more context-specific than sensitivity analysis, is to help understand how the uncertainty in the measurement of parameters can influence model projections [Mishra et al., 2011].

Additionally, mathematical models provide guidance for the prevention and control of HIV. Models have been used to monitor and evaluate the potential effectiveness and cost-effectiveness of proposed or ongoing public health interventions, to identify the most effective intervention in particular settings (and under varying assumptions) and to predict potential unintended consequences of interventions [Boily et al., 2007b, Boily et al., 2008, Pickles et al., 2010, Williams et al., 2006]. Mathematical models can be especially useful for evaluating the effects of interventions in situations where it is unfeasible to institute community-based randomized trials (CBRTs), the current gold standard for evaluating interventions. CBRTs offer many advantages; however, they are often very expensive, require large sample sizes and raise ethical concerns. The complex transmission dynamics of HIV also make design and interpretation of CBRTs difficult; this may mean that the conclusions from CBRTs have limited relevance in the real world. Modelling is less expensive, has fewer ethical concerns, can be simple or complex, and is easily incorporated into routine monitoring and assessment activities [Garnett 2002, Ghani and Boily 2003].

Mathematical models of transmission dynamics can either be individual-based or compartmental. Individual-based models represent each individual in a population (and their sexual contacts) uniquely, assigning each individual a specific set of characteristics (e.g., regarding age, sexual behaviour, or sex partnering patterns) [Garnett 2002, Mishra et al., 2011]. In this way, individual-based models can represent complex sex partnering patterns between individuals in a population as well as heterogeneity in terms of different characteristics [Mishra et al., 2011]. The disadvantage of an individual-based approach is that it can be challenging to interpret which parameters are important to the epidemic [Garnett 2002]. Individual-based models are stochastic models, which incorporate a probabilistic framework whereby randomness or chance is taken into account. In stochastic models, transition to the next possible set of events occurs according to an assigned probability [Garnett 2002, Mishra et al., 2011]. Compartmental models divide the overall population into sub-populations (i.e., compartments), to represent the different stages of infection experienced by individuals as the infection progresses [Boily and Masse 1997, Cassels et al., 2008, Garnett 2002]. Compartmental models capture additional heterogeneity in a population by stratifying the population (which is already stratified according to the progression of infection) into a number of sub-populations (e.g., by level of sexual activity or by sex partnering patterns). Compartmental models can be either deterministic or stochastic. Deterministic models assume that multiple runs of the model using the same parameters and starting conditions will provide the exact same results (i.e., events occurring in the model are not subject to chance) [Cassels et al., 2008, Garnett 2002, Mishra et al., 2011]. Deterministic models reflect the average behaviour of a system [Mishra et al., 2011]. Typically, inferences on the transmission dynamics of infection for populations have been made with the use of compartmental deterministic models.

Recent mathematical modelling work of HIV in India has provided important insights into the transmission dynamics of infection as well as implications for prevention. Compartmental deterministic models have been used to predict HIV prevalence over time [Venkataramana and Sarada 2001] as well as to examine important factors influencing HIV transmission and differences in HIV prevalence across districts in Karnataka state, including certain biological factors, sexual behaviour factors and migration-related factors [Deering et al., 2008, Williams et al., 2006]. These models also have been incorporated in research conducted as part of the monitoring and evaluation of the Avahan AIDS Initiative in southern India [Boily et al., 2007b]. Collectively, this body of research has examined the potential impact of the Avahan AIDS Initiative on HIV prevalence and assessed if observed declines in antenatal HIV prevalence among women could be attributed to the intervention. The Avahan AIDS Initiative evaluation has assessed if observed increases in condom use among FSWs could explain declines in FSW HIV prevalence and described the relative contribution of commercial sex to the HIV epidemic (these studies are described in more detail in Section 2.3) [Boily et al., 2008, Pickles et al., 2010]. While these studies have provided important information from multiple settings in southern India, important gaps remain, including a thorough exploration of heterogeneity in sexual structure of FSWs and their male partners as well as an examination of how sexual structure influences HIV prevalence. Investigating the hypothesized relationship between observed differences in sexual structure and HIV prevalence would help identify important factors defining sexual structure (e.g., distributions of the numbers of clients of FSWs) to HIV transmission on a population level both within geographic regions (e.g., by place of solicitation including brothels, homes and public places) and across geographic regions (e.g., by district). This information also could help predict the impact of the intervention in settings with different sexual structures.

2.3 HIV INTERVENTIONS, CONDOM USE AND SEXUAL STRUCTURE

HIV prevention approaches and intervention effectiveness

HIV prevention interventions among FSWs have employed a variety of individual-level approaches that focus on changing sexual behaviour, particularly condom use (e.g., through condom promotion and education) [Shahmanesh et al., 2008]. More recently, the importance of structural-environmental factors in shaping HIV vulnerability, including among sex workers, has been recognized [Buzdugan et al., 2009, Coates et al., 2008, Gupta et al., 2008, Harcourt and Donovan 2005, Kerrigan et al., 2003, Kerrigan et al., 2006, Parker et al., 2000, Poundstone et al., 2004, Shannon et al., 2008a, Shannon et al., 2009b]. Sex work-related harms are thought to be shaped by risk environments, in which multiple factors interact to produce harm. These environments could include, for example, social, economic, policy, physical environments that operate on both micro- and macro-levels to influence risk to women's health, safety and well-being [Rhodes 2002, Rhodes et al., 2005]. The behaviours (high or low-risk) of individuals both *act on* and *react to* these environments. For example, the use of condoms by FSWs can be seen as a function of their desire or knowledge regarding condom use, as well as environmental factors such as the availability of condoms, cultural perceptions of condoms by male partners, and gendered power relations.

Interventions with behavioural, structural and community-level components have been developed and tested in many countries to reduce risk for HIV [Ainsworth et al., 2003, Hogle et al., 2002, Jana et al., 2004, Jana et al., 2006]. There are a number of examples where empirical evidence suggests that the impacts of large-scale community-structural prevention programmes have been positive [Hanenberg et al., 1994, Hogle et al., 2002, Jana et al., 2004, Surasiengsunk et al., 1998]. Notably, in response to high rates of HIV and STIs among FSWs in the early 1990s, several countries in east Asia instituted a 100% condom use campaign intended to empower FSWs to demand condom use with clients, and increase FSWs' access to STI testing and treatment. This programme is thought to have contributed to dramatic declines in STIs and HIV in Thailand and Cambodia, as well as influence similar campaigns across Asia [Hanenberg et al., 1994, Jana et al., 2006, Rojanapithayakorn 2006]. An adaptation of the 100% condom use campaign in the Dominican Republic was informed and modified by community members to include community mobilization and collectivization of sex workers, as well as increased clinical services and education through social messages. Exposure to this intervention was associated with improvements in condom use with occasional clients and regular partners, and reductions in STI prevalence [Kerrigan et al., 2003, Kerrigan et al., 2006]. The Sonagachi Project in Kolkata, India implemented a community empowerment model for sex workers that framed health risks to sex workers as occupational hazards, focusing on addressing HIV risk factors at the group level (e.g., changing social relationships), community level (e.g., addressing community barriers and resources) and individual level (e.g., education regarding HIV prevention and treatment). As a result, large increases in condom use have been observed and HIV prevalence remains low in FSWs associated with the Sonagachi Project [Cohen 2004, Jana et al., 2004, Jana et al., 2006].

Theoretical studies that use empirical data to rigorously evaluate specific core group interventions are rare, but can be useful in understanding the impact of interventions directed toward core groups (e.g., FSWs and their clients) on HIV prevalence in FSWs and general populations. Nagelkerke et al (2000) suggested that a single intervention targeted toward FSWs in India may be enough to control the epidemic, decreasing HIV prevalence in the population to below 1% after about 30 years [Nagelkerke et al., 2002]. However, these results should be interpreted with caution, because of the limited available data at the time, the simplicity of the model, and the lack of an uncertainty analysis. More recently, a World Bank report summarized recent observational and mathematical modelling analysis of the impact of the Projet SIDA intervention, implemented in Cotonou, Benin since 1993 [Lowndes et al., 2008]. Results suggested that positive outputs of the intervention (e.g., increased condom use and decreased gonorrhoea prevalence) among FSWs over time may have contributed to a reduction in prevalence and incidence of HIV in both FSWs as well as the general population of women [Boily et al., 2002, Lowndes et al., 2008]. Over 15 years of the intervention, 63% and 51% of new infections were estimated to have been averted in FSWs and women in the general population, respectively. It is difficult to assess how generalizable these results in Cotonou, Benin are to other settings. However, they provide some evidence for the importance of designing sustained interventions for specified core groups in order to prevent the spread of infection in core groups as well as the general population.

As previously discussed in Chapter 1, the intervention being examined by the current dissertation is the Avahan AIDS Initiative. The Avahan AIDS Initiative is a large-scale intervention operating since 2003. It is designed to take a comprehensive approach to reducing HIV, first in specific core (e.g., FSWs; MSM) and bridge groups (e.g., clients of FSWs), using community empowerment and structural interventions to address both proximal and distal determinants of risk for core and bridge groups [Avahan, the India AIDS Initiative - the Business of HIV prevention at Scale 2008, Piot 2010]. The intervention focuses on the prevention of sexual transmission of HIV in these groups in four southern states, which are most affected by HIV, and injection drug use transmission in two northern states. The intervention is intended to be brought to scale to reduce HIV among the general population. Since the beginning of the intervention, there is evidence emerging that condom use among FSWs has increased and STI prevalence has decreased [Ramesh et al., 2010, Reza-Paul et al., 2008].

As part of the evaluation of the intervention, a series of mathematical modelling studies of increasing complexity have examined the potential and early impacts of the intervention in the four southern states among FSWs and clients, who are directly targeted by the intervention [Boily et al., 2007b, Boily et al., 2008, Williams et al., 2006]. Complementary mathematical modelling analysis has been conducted to help understand the extremely rapid decline in HIV prevalence between 2004 and 2006, and 2007 (26% and 43%, respectively) observed among women attending antenatal clinics. The analysis suggested that it was unlikely that the large decline in HIV among pregnant women could be solely attributable to the intervention implemented in FSWs. This was especially the case since the observed decline in FSWs' HIV prevalence was not large enough over the same period of time to influence the antenatal prevalence to the extent observed, even if the intervention would likely be effective at reducing FSW HIV prevalence and antenatal clinic prevalence in the longer-term [Boily et al., 2008]. Interim mathematical modelling analysis also suggested that the observed declines in HIV prevalence in two Avahan districts (Mysore and Belgaum) were consistent with self-reported increases in condom use by FSWs [Lowndes et al., 2010, Pickles et al., 2010, Ramesh et al., 2010] and lent some support that increased self-reported condom use has contributed toward reducing HIV spread following the Avahan AIDS Initiative.

HIV prevention and sexual structure

In addition to influencing condom use, some interventions aimed at general populations have incorporated other behaviour change programs that are related to sexual structure, such as delaying the age at first sex, encouraging individuals to be monogamous to their main partner (and thus decreasing the numbers of new partners) or decreasing overall numbers of casual partners [Hogle et al., 2002]. In Uganda, the striking decline in HIV prevalence in general populations in the past decade is hypothesized to be due, at least in part, to the impact of widespread changing social attitudes due to the 'ABC' programme (abstinence, being faithful, condom use) [Hogle et al., 2002, Shelton et al., 2004]. It is hypothesized that governmental and national policies that supported the development of a multi-level system of support have contributed to the decreases in prevalence [Gupta et al., 2008]. In a theoretical study (not based in a particular study setting), Garnett et al (2008) compared the impact of reductions of the numbers of sex partners or increases in condom use [Garnett et al., 2008]. Consistent with other studies [Pinkerton et al., 2002, Pinkerton et al., 2003], they found that a reduction of the numbers of sex partners was more important than increases in condom use for bacterial infections with high infectivity, whereas the impact of these two measures was similar for viral infections, with lower infectivity [Garnett et al., 2008]. For infections with low infectivity, such as HIV, even a small increase in condom use was effective at reducing prevalence [Garnett et al., 2008].

Some features of the sexual structure of populations (e.g., types of sex partnering patterns) could also influence the effectiveness of HIV interventions. As described previously, condom use levels can vary according to FSWs' type of sexual partner (i.e., repeat versus occasional clients; commercial clients versus intimate partners) [Hanck et al., 2008, Malta et al., 2008, Reza-Paul et al., 2008], and interventions have typically focused on changing sexual behaviour among FSWs by increasing their condom use with commercial clients, since the contribution of sex partnerships of FSWs and clients to HIV epidemics is estimated to be high in many settings [Lowndes et al., 2002, Lowndes et al., 2008, Vickerman et al., 2010]. Indeed, dramatic increases in reported condom use with occasional clients of FSWs has been observed post-intervention in some settings, though not necessarily within intimate or non-commercial partnerships of FSWs [Hanenberg et al., 1994, Hogle et al., 2002, Jana et al., 2004, Ramesh et al., 2010, Reza-Paul et al., 2008, Rojanapithayakorn 2006]. However, there are examples where this does occur [Kerrigan et al., 2006]. Other features of sexual structure, such as the number of sex acts with different partners, could impact the effectiveness of interventions. In Garnett et al

(2008), the benefits of condom use depended on the number of sex acts per partnership, with increased number of sex acts requiring higher condom use for the same level of effectiveness [Garnett et al., 2008]. Given that the effectiveness of interventions for FSWs in decreasing risky sexual behaviour may vary for different types of sex partnerships, and that sexual structure can vary substantially across different contexts, the overall effectiveness of interventions may vary across populations with different sexual structures and in different contexts.

2.4 SUMMARY OF THE LITERATURE REVIEW

The primary aim of this review was to provide an overview of the elements relevant to the forthcoming studies described in the current dissertation. The review provided a summary of the historical and emerging research literature and highlighted the gaps in knowledge that this dissertation will address. The important influence of features of sexual structure (i.e., numbers of sex partners and sex partnering patterns) on individual HIV risk was described. Next, the relationship between sexual structure and HIV prevalence on a population level was delineated. Finally, the review described research on interventions to reduce HIV rates, with a focus on southern India, and their relationships to sexual structure. Chapters 3 through 5 will follow, each comprising an analysis based on the research questions outlined in Chapter 1 and guided by the content of this literature review.

CHAPTER 3

FACTORS ASSOCIATED WITH THE NUMBERS OF CLIENTS OF FEMALE SEX WORKERS IN SOUTHERN INDIA

3.1 INTRODUCTION

Globally, women who engage in commercial sex work are at high risk for HIV infection through sexual transmission [2006 AIDS epidemic update. 2006]. The risk of HIV infection for female sex workers (FSWs) is known to be influenced by various social and environmental factors (e.g., increased social and economic vulnerability within a male-dominated society; reduced education; marginalization and criminalization of sex work; limited access to prevention and treatment programs and services) [2006 AIDS epidemic update. 2006, 2006 report on the global HIV/AIDS epidemic: May 2006 2006, Blanchard et al., 2005, Boerma and Weir 2005, Dandona et al., 2006, Gangopadhyay et al., 2005, HIV Epidemic Update 2004, Soskolne 2007]. The risk of acquiring and transmission HIV is directly influenced by numbers of sex partners, the majority of whom are commercial clients, and factors influencing the probability of transmission per sexual contact (e.g., condom use, types of sex acts) [Anderson and May 1991, Boily et al., 2009, Garnett et al., 2008, Ramesh et al., 2008].

Previous research has focused on understanding the factors associated with condom use and HIV or other sexually transmitted infections (STIs), in order to better identify which FSWs are at higher risk for infection. While condom use and the number of unprotected sex acts influence the risk of infection, a partnership must first take place in order for protected and un-protected sex acts to occur. Thus, the number of commercial sex partners conveys important information on the raw potential of HIV acquisition and transmission among FSWs. However, few studies have investigated the factors influencing the numbers of clients that FSWs have. It is important to study the determinants of the number of clients that FSWs have at the individual-level because, with other risk factors being equal (e.g., same condom use, infection status of their partner), women with higher numbers of clients are at higher risk of being exposed to HIV and STIs. The risk of being exposed to other health risks, such as physical violence and sexual assault, also increases with higher numbers of clients [Beattie et al., 2010]. In addition, HIV/STI programmes are often developed with a focus on women with a high number of clients [Hogle et al., 2002, Sarkar 2010, Shelton et al., 2004].

The HIV epidemic in India continues to be a global concern, with the majority of HIV infections transmitted sexually and concentrated in four states in southern India within several high-risk groups, including FSWs and men who have sex with men[12] [2006 report on the global HIV/AIDS epidemic: May 2006 2006, Steinbrook 2007]. HIV prevalence in FSWs has been found to vary substantially across and within states, including Karnataka State, a high-prevalence state in southern India, and within Karnataka's districts (sub-state administrative areas) [Becker et al., 2007, Ramesh et al., 2008]. In this analysis, the primary objectives were to examine geographic heterogeneity in reported numbers of commercial sex clients of FSWs in southern India across districts and to investigate the extent to which social and environmental factors were associated with the numbers of clients of FSWs. The results from this research will help inform the continued development of prevention interventions to reduce the HIV risk faced by these women.

[12] In several areas in north India, the epidemic is spread primarily through injection drug use.

3.2 METHODS

Study design and sampling

The five districts in Karnataka in which the survey instrument, the Integrated Biological and Behavioural Assessments (IBBA), was administered were chosen based on the socio-cultural regions of the state and high-risk population size [Ramesh et al., 2008]. Details on sampling are found in Ramesh et al (2008) [Ramesh et al., 2008]. Normalized weights were calculated to account for sampling design. The IBBAs were conducted in 2004-05 as part of the Avahan AIDS Initiative, a large-scale targeted HIV prevention intervention implemented in southern India [Avahan, the India AIDS Initiative - the Business of HIV prevention at Scale 2008].

Survey organization and methods

The IBBA collected information on socio-demographics, sexual behaviour, sex work environments and exposure to the intervention. Biological samples for HIV were also collected. Statutory approval for the conduct of the IBBA and its protocols was obtained by the Government of India's Health Ministry Screening Committee. The Karnataka Health Promotion Trust implemented the surveys. The surveys were administered through face-to-face interviews and were conducted anonymously, with no names or personal identifiers recorded. A detailed and standardized consent process was implemented for each respondent.

Outcome measure

The outcome measure, number of commercial sex clients per month, was derived from multiplying responses to the survey item "How many clients did you entertain on your last working day?" by responses to "How many days in a typical month do you entertain clients?"

Explanatory variables

This analysis was informed by previous work by Rhodes et al (2002), who asserts that micro- and macro-level risk factors intersect with distinct environmental features (e.g., social, economic, physical) to produce overall patterns of risk [Rhodes 2002]. Using data available in the IBBA, this analysis included social factors (age, marital status, duration of sex work and the amount that women charged per sexual encounter) and environmental factors. Environmental factors included the sex work environment of FSWs, which was defined as the places where women solicited for clients. Sex work environment was grouped into three categories: (1) home-based (home; rented room); (2) brothel-based (lodge; *dabha* [road-side lodge-type establishment]; bar/night club; brothel); and (3) public places-based (vehicle; public places). Information on FSWs' other paid employment was also collected (sex work as sole income versus had other paid work) and literacy levels, defined by whether FSWs were able to read and write. Exposure to the intervention was assessed by whether or not women had been contacted by intervention staff and if they were members of a sex worker collective. Risk perception determinants were assessed, including perceived risk for HIV infection and whether ever taken an HIV test. The impact of district of residence was also examined, by stratifying the analysis by district (see below). The relationships between numbers of clients per month and: (1) frequency of inconsistent condom use (defined as 'never', 'sometimes' or 'frequent' reported condom use with clients, versus 'always'); and (2) HIV prevalence, were also assessed.

Statistical analysis

Statistical analysis was conducted using SAS Version 9.1.3 [SAS 2002-03]. For each district, descriptive statistics were calculated for sample characteristics and for the outcome measure, overall and by each explanatory variable. Analysis of variance was used to compare means between districts, and chi-squared tests were used to compare differences between districts on sample characteristics, with exact tests used when there were empty cells [Rosner 2005]. Since the outcome measure was non-normally distributed, differences in the median clients per month across districts were compared using non-parametric Kruskal-Wallis and Wilcoxon Rank Sum tests. The average (mean) numbers of clients per month was also presented and discussed, because this is the more common measure of centrality used in the literature. Negative binomial regression was used because the outcome was a count variable and overdispersed; models were constructed for each district [Hilbe 2007]. Since observations from FSWs sampled from the same cluster were not independent, generalised estimating equations (GEEs) were used [Cole 2001, Johnston 1993, Orelian 2001, Smith and Smith 2006]. GEE-based analyses are appropriate for this study, since GEE describes the population-averaged effects of the covariates of interest on the response variable [Fitzmaurice et al., 2004, Hu et al., 1998, Smith and Smith 2006]. These methods provided standard errors adjusted by repeated observations per person using an exchangeable correlation structure [Cole 2001]. Multivariable incidence rate ratios (adjusted incidence rate ratios=AIRRs) were reported from negative binomial regression analysis [Hilbe 2007]. Inclusion decisions in the multivariable models were based on significance at the $p<0.10$ level using results from bivariate analyses, or if they were perceived to be important confounders *a priori* (age and work environment) [Johnston 1993]. Condom use and HIV prevalence were not assessed as predictive explanatory variables for the numbers of clients per month. Since “age” and “the duration of sex work” were found to be correlated, only age was entered into the models. All *p*-values are two-sided.

3.3 RESULTS

Sample characteristics

Table 3.1 summarises sample characteristics of FSWs in the five districts. The sample sizes for Bangalore, Belgaum, Bellary, Mysore and Shimoga were 676, 385, 426, 429 and 394 (N=2310) respectively. There was significant heterogeneity across districts; the only factor that did not differ significantly across districts was feeling at risk for HIV (p=0.10). The average age of FSWs was highest in Shimoga (31.6 years) and lowest in Mysore (30.0 years).

Table 3.1: Sample characteristics of female sex workers in five districts in Karnataka state, India.[1,2]

Factor	District					Chi-square
	Bangalore N=676	Belgaum N=385	Bellary N=426	Mysore N=429	Shimoga N=394	
	Mean (N) or Prevalence (N)					
SOCIAL						
Age (years)	30.7 (675)	31.4 (384)	30.7 (426)	30.0 (429)	31.6 (394)	5.3†
Duration of sex work (years)	3.9 (675)	9.6 (382)	8.5 (426)	4.5 (429)	5.5 (393)	72.6†
Marital status						
Married	43.2 (306)	17.4 (62)	23.0 (115)	4.9 (21)	45.1 (176)	684.2†
Cohabiting	4.9 (39)	9.0 (34)	8.7 (32)	31.2 (134)	3.7 (16)	
Single	51.8 (329)	54.5 (206)	57.8 (233)	63.9 (274)	51.3 (201)	
Other	0.1 (1)	19.1 (82)	10.5 (47)	-	-	
Amount charged per sexual encounter (rupees[3])	360.3 (676)	80.9 (384)	122.3 (425)	170.9 (429)	138.7 (386)	273.7†
ENVIRONMENTAL						
Work environment						
Home-based	13.4 (157)	29.0 (130)	60.6 (200)	11.7 (50)	52.8 (215)	453.9†
Brothel-based	3.6 (48)	33.6 (97)	7.0 (43)	0.5 (2)	5.2 (22)	
Public-based	83.0 (471)	37.4 (157)	32.4 (184)	87.9 (377)	42.0 (155)	
Sex work sole income						
Yes	56.7 (371)	56.3 (226)	71.3 (291)	44.8 (192)	79.1 (303)	116.2†
No	43.3 (296)	43.7 (154)	28.7 (136)	55.2 (237)	20.9 (81)	
Education						
Cannot read/write	52.2 (363)	82.0 (313)	66.1 (303)	24.5 (105)	38.5 (157)	181.0†
Can read/write	47.8 (313)	18.0 (71)	33.9 (124)	75.5 (324)	61.5 (237)	
Contacted by staff						
Yes	89.7 (603)	95.8 (366)	91.3 (379)	n/a[2]	82.2 (326)	30.0†
No	10.4 (71)	4.2 (18)	8.7 (48)		17.8 (66)	
Member of collective						
Yes	6.6 (45)	19.3 (88)	24.2 (99)	n/a	3.9 (17)	121.0†
No	93.4 (45)	80.7 (295)	75.8 (328)		96.1 (373)	
Feel at risk for HIV						
Yes	29.8 (201)	27.4 (115)	27.5 (108)	n/a	24.3 (83)	6.1
No	70.2 (446)	72.6 (243)	72.5 (271)		75.7 (254)	
Ever taken HIV test						
Yes	39.6 (254)	35.7 (126)	21.2 (87)	n/a	25.6 (85)	39.9†
No	60.4 (406)	64.3 (248)	78.9 (320)		74.4 (242)	

[1]Significance: * *p*<0.05; † *p*<0.01.
[2] n/a means that the survey item was not asked of respondents in a district; - means that there were no observations for that category; sample size. may vary across factors, since not all observations were available for all factors; N represents the maximum sample of respondents by district
[3]At the time of writing this dissertation, one rupee was equal to 0.0213 $US.

Risk characteristics

Table 3.2 summarises HIV prevalence, inconsistent condom use and client volume across districts. HIV prevalence and numbers of clients per month varied significantly across districts; HIV prevalence was higher in districts with higher average (mean) and median clients per month. Belgaum had the highest average and median clients per month and HIV prevalence (56.9 and 40.0; 33.9%), more than twice that in Shimoga, which had the lowest (26.1 and 16.0; 9.7%). Clients per day and days worked per month were positively associated in each district ($p<0.001$). These results suggest that districts in which FSWs have higher sexual activity and spend more time doing sex work also have higher FSW HIV prevalence. Figure 3.1 illustrates the distribution of clients per month by district. About 30% of Belgaum's respondents reported more than 60 clients per month, while this was only about 10% in Shimoga, Mysore and Bangalore. Belgaum had the lowest fraction of respondents reporting 15 clients or less every month (17%), while Shimoga had the largest (50%).

Table 3.3 describes the average (mean) and median clients per month of respondents in each district by social and environmental factors. In all districts, the median number of clients per month was significantly different according to work environment, marital status and sex work as sole income, with the effects of work environment differing geographically. Brothel-based FSWs had the highest clients per month, whereas home-based FSWs had the lowest clients per month (except for Bangalore). Married respondents had the lowest average clients per month across districts, with cohabiting FSWs having the highest average clients per month in all districts except Bangalore. FSWs who relied on sex work as their sole source of income consistently reported having more clients per month than those with an additional source of income. Literacy levels, being a member of a collective, feeling at risk for HIV, and ever having taken an HIV test were also significantly associated with clients per month in several districts. The numbers of clients per month were significantly higher among FSWs who were HIV positive in Belgaum, compared to those who were HIV negative. The numbers of clients per month were significantly higher among FSWs who reported using condoms inconsistently in

Mysore and significantly lower in Bellary, compared to those who reported using condoms consistently.

Table 3.2: HIV prevalence, inconsistent condom use and measures of centrality for the numbers of clients of female sex workers per day, days entertaining clients per month and clients per month in Karnataka state, India (bivariate associations by district).[1]

Variable	Measure of centrality	District					Kruskal-Wallis or Wilxcon/ Chi-squared test
		Belgaum	Mysore	Bellary	Bangalore	Shimoga	
HIV	Prevalence %	33.9	26.1	15.5	12.7	9.7	366.6†
	(**rank**)	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	
Inconsistent condom use[2]	Prevalence %	9.1	64.6	27.2	22.0	33.8	118.1†
	(**rank**)	**(5)**	**(1)**	**(3)**	**(4)**	**(2)**	
Clients per month	Mean	56.9	30.3	46.4	34.5	26.1	
	(**rank**)	**(1)**	**(4)**	**(2)**	**(3)**	**(5)**	
	Variance	3038.7	730.5	3780.0	743.5	794	
	Range	0-300	1-189	0-750	0-270	1-180	
	25th percentile	20	10	12	15	8	
	Median	40	20	30	30	16	162.3†
	(rank)	**(1)**	**(4)**	**(2.5)**	**(2.5)**	**(5)**	
	75th percentile	75	40	60	45	30	
Clients entertained on the last day (1)	Mean	2.8	1.9	2.5	2.1	2.0	
	(**rank**)	**(1)**	**(5)**	**(2)**	**(3)**	**(4)**	
	Variance	97.87	320.0	86.9	132.1	72.4	
	Range	1-15	1-22	1-25	1-10	1-8	
	25th percentile	2	1	1	1	1	
	Median	2	1	2	2	1	100.1†
	(rank)	**(1.3)**	**(4)**	**(1.3)**	**(1.3)**	**(4)**	
	75th percentile	3	2	3	3	2	
Days entertain clients per month (2)	Mean	18.2	15.3	15.8	15.5	11.5	
	(**rank**)	**(1)**	**(4)**	**(2)**	**(3)**	**(5)**	
	Variance	607.1	2973.6	577.0	915.6	382.3	
	Range	0-29	1-30	0-30	0-30	1-30	
	25th percentile	15	9	10	12	8	
	Median	20	15	15	16	12	191.9†
	(rank)	**(1)**	**(3.5)**	**(3.5)**	**(2)**	**(5)**	
	75th percentile	25	20	20	20	15	
Correlation between (1) and (2)	Spearman's correlation coef.	0.41†	0.23†	0.49†	0.34†	0.45†	

[1]Significance: * $p<0.05$; † $p<0.01$
[2]Inconsistent condom use is defined as condom use that is less than 100% or always

Figure 3.1: Fraction of respondents with different average numbers of clients per month in Karnataka state, India.

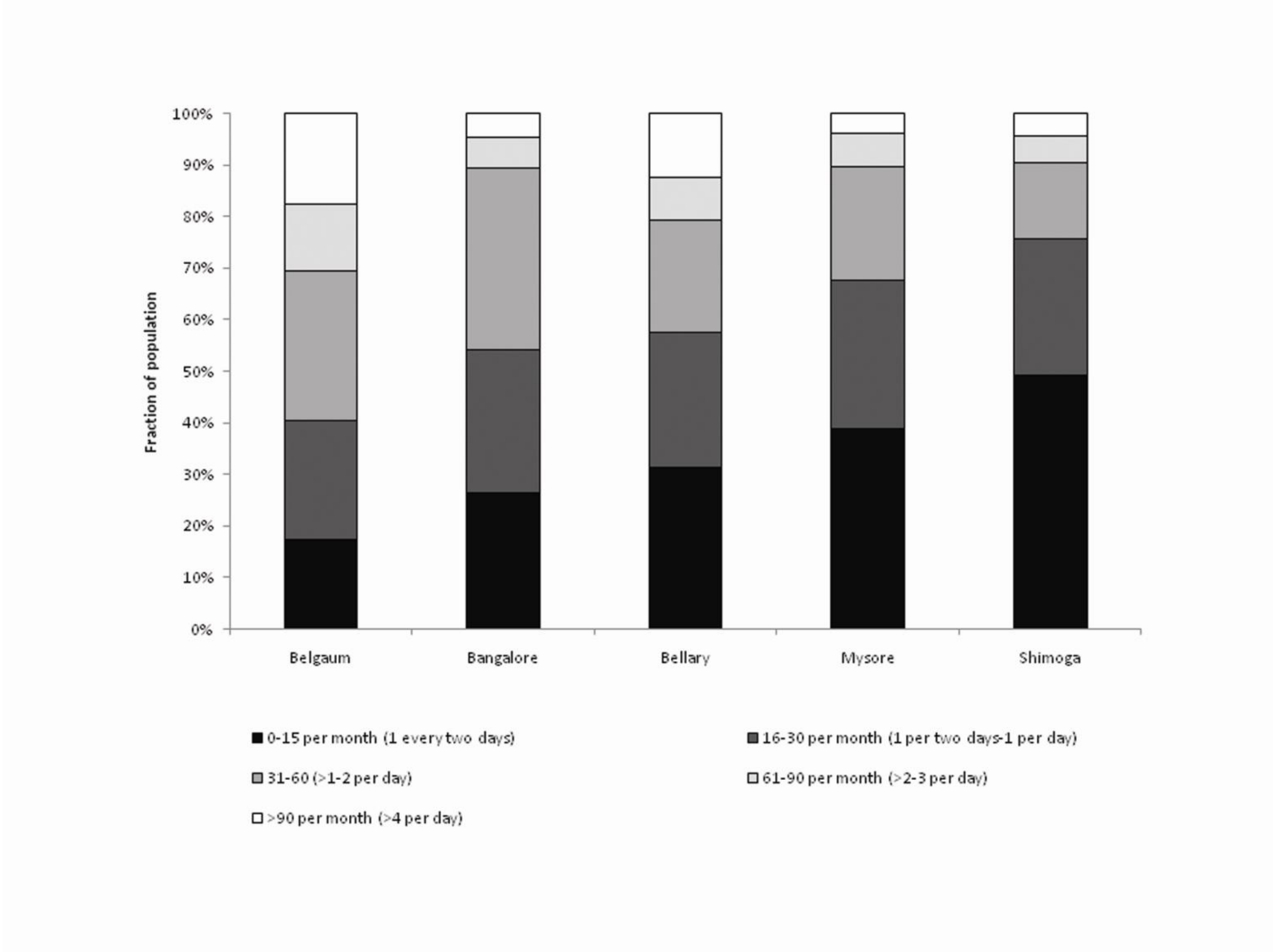


Table 3.3: Average (median) numbers of clients per month of female sex workers by social and environmental factors in Karnataka state, India, and Kruskal-Wallis (K-W) tests.[1,2]

Explanatory variable	District				
	Bangalore	Belgaum	Bellary	Mysore	Shimoga
SOCIAL					
Marital status					
Married	31.3 (24)	44.5 (30)	41.8 (20)	19.0 (9)	21.3 (15)
Cohabiting	34.5 (32)	90.7 (75)	62.3 (30)	35.8 (25)	42.5 (40)
Single	37.3 (32)	55.7 (40)	44.9 (75)	28.5 (20)	29.0 (16)
Other	15.0 (15)	55.8 (46)	51.4 (40)	-	-
K-W	11.0*	14.3†	11.7†	13.0†	14.9†
ENVIRONMENTAL					
Work environment					
Home-based	32.6 (24)	44.4 (28)	34.8 (24)	20.9 (15)	21.3 (14)
Brothel-based	30.6 (24)	79.0 (60)	151.1 (130)	36.0 (36)	40.5 (36)
Public-based	35.0 (30)	47.0 (36)	46.0 (30)	31.5 (24)	30.1 (20)
K-W	7.6*	37.7†	29.3†	34.1†	27.2†
Sex work sole income					
Yes	37.5 (36)	75.3 (60)	77.1 (48)	35.6 (25)	36.1 (20)
No	32.2 (24)	43.0 (30)	33.9 (24)	23.9 (16)	23.3 (15)
K-W	8.6†	29.7†	63.0†	18.7†	6.3*
Education					
Cannot read/write	35.6 (30)	58.2 (46)	43.8 (30)	32.0 (24)	26.1 (16)
Can read/write	33.6 (28)	50.9 (30)	51.4 (20)	25.3 (15)	26.1 (15)
K-W	1.6	0.7	0.3	7.7†	0.2

Explanatory variable	District				
	Bangalore	Belgaum	Bellary	Mysore	Shimoga
Contacted by staff					
No	35.5 (22)	34.3 (25)	66.2 (30)	n/a	29.2 (13)
Yes	34.4 (30)	57.9 (44)	44.6 (30)		25.4 (16)
K-W	1.8	2.3	0.1		0.5
Member of collective					
No	34.5 (30)	56.9 (40)	46.3 (25)	n/a	25.1 (15)
Yes	35.3 (30)	56.9 (48)	46.8 (30)		42.8 (40)
K-W	0.8	0.4	1.3		8.6†
Feel at risk for HIV					
No	33.4 (44)	56.0 (36)	47.0 (30)	n/a	24.1 (15)
Yes	38.7 (36)	56.5 (48)	41.4 (24)		29.9 (24)
K-W	15.6†	1.3	0.3		5.3*
Ever taken HIV test					
No	33.1 (25)	59.3 (45)	41.2 (25)	n/a	22.2 (15)
Yes	37.4 (32)	52.9 (32)	60.4 (40)		32.9 (24)
K-W	6.5*	0.4	7.7†		9.9†
Condom use					
Inconsistent[3]	36.90 (36)	44.11 (30)	35.53 (20)	35.18 (27)	26.19 (15)
Consistent	34.29 (28)	58.22 (40)	50.46 (30)	23.57 (18)	26.47 (16)
K-W	0.2	2.3	11.3†	16.0†	2.6
HIV prevalence					
No	34.13 (30)	52.70 (40)	47.18 (30)	29.54 (20)	25.25 (15)
Yes	37.02 (24)	64.94 (50)	47.52 (30)	32.57 (24)	37.42 (26)
K-W	1.1	4.0*	0.2	0.5	2.4

[1]Significance: * $p<0.05$; † $p<0.01$.
[2]n/a means that the survey item was not asked of respondents in a district; - means that there were no observations for that category.
[3]Inconsistent condom use is defined as condom use that is less than 100% or always.

Multivariable analysis

Table 3.4 displays adjusted incidence rate ratios (AIRR) from multivariable analysis for the associations between social and environmental factors and clients per month. None of the districts had identical sets of factors significantly associated with clients per month, although some similarities were observed. In four districts, women who relied on sex work as sole income had higher rates of clients per month, even after adjusting for other social and environmental factors. Single FSWs and FSWs cohabiting with a partner in all districts had higher rates of clients per month relative to married FSWs; this relationship was statistically significant in Belgaum, Mysore and Shimoga for cohabiting FSWs, and for single FSWs in Mysore.

Rates of clients per month were negatively associated with age in all districts; however, this relationship was only significant in Belgaum, Bellary and Mysore (clients per month decreased by 3-4% for each one-year increase in age). Compared to home-based FSWs, brothel-based FSWs in Belgaum and Shimoga had 50% and 60% higher rates of clients per month (AIRR: 1.5, 95% CIs: 1.1-2.0); and AIRR: 1.6, 95% CIs: 1.0-2.7 respectively), whereas public places-based FSWs in Mysore had more clients than home-based FSWs (AIRR: 1.4, 95% CIs: 1.1-1.8). In Mysore, amount charged per sexual encounter was significantly negatively associated with clients per month (clients per month decreased by 2% for a 10-rupee increase in amount charged). FSWs in Mysore who could not read or write had 21% higher rates of clients (AIRR: 1.2, 95% CIs: 1.0-1.5). In Bellary, FSWs who did not feel at risk for HIV had rates of clients per month that were 40% higher than those who did (AIRR: 1.4, 95% CIs: 1.0-1.9). However, in Shimoga, FSWs who had not ever taken an HIV test had 35% (AIRR: 0.7, 95% CIs: 0.5-0.9) lower rates than FSWs who had. In Shimoga, FSWs who were not members of a collective had 38% lower rates of clients per month (AIRR: 0.6, 95% CIs: 0.4-1.0).

Table 3.4: Adjusted multivariable incidence rate ratios (AIRR), 95% confidence intervals (95% CIs) and *p*-values for the relationship between social and environmental factors and rates of clients per month of female sex workers in Karnataka state, India.[1,2,3]

Explanatory variable	District									
	Bangalore		Belgaum		Bellary		Mysore		Shimoga	
	AIRR	95% CIs	AIRR	95% CIs	AIRR	95% CIs	AIRR	95% CIs	AIRR	95% CIs
SOCIAL										
Age	0.99	0.97-1.00	0.96†	0.94-0.99	0.96†	0.94-0.98	0.98†	0.96-0.99	0.99	0.97-1.00
Duration of sex work	/	/	/	/	/	/	/	/	/	/
Marital status										
Cohabiting	/	/	1.56*	1.04-2.34	/	/	1.87†	1.29-2.71	1.59†	1.16-2.18
Single			1.26	0.91-1.77			1.63†	1.14-2.35	1.19	0.96-1.48
Other			1.17	0.84-1.62			-		-	
Married			1.0 (ref)				1.0 (ref)		1.0 (ref)	
Amount charged	1.00	1.00-1.01	/	/	/	/	0.99†	0.98-1.00	/	/
ENVIRONMENTAL										
Work environment										
Public-based	0.96	0.66-1.38	1.04	0.82-1.31	1.27	0.86-1.87	1.42†	1.11-1.80	1.15	0.87-1.53
Brothel-based	0.76	0.51-1.15	1.49†	1.12-1.97	1.60	0.88-2.90	1.87	0.63-5.95	1.64*	1.02-2.65
Home-based	1.0 (ref)		1.0 (ref)		1.0 (ref)		1.0 (ref)		1.0 (ref)	
Sex work sole income										
Yes	1.15	0.98-1.36	1.51†	1.16-1.98	1.72†	1.17-2.52	1.42†	1.22-1.66	1.28*	1.00-1.66
No	1.0 (ref)		1.0 (ref)		1.0 (ref)		1.0 (ref)		1.0 (ref)	
Education										
Cannot read/write	/	/	/	/	/	/	1.21*	1.01-1.46	/	/
Can read/write							1.0 (ref)			

Explanatory variable	District									
	Bangalore		Belgaum		Bellary		Mysore		Shimoga	
	AIRR	95% CIs	AIRR	95% CIs	AIRR	95% CIs	AIRR	95% CIs	AIRR	95% CIs
Contacted by staff										
No	/	/	/	/	/	/	n/a	n/a	/	/
Yes										
Member of collective										
No	/	/	/	/	/	/	n/a	n/a	0.62*	0.40, 0.95
Yes									1.0 (ref)	
Feel at risk for HIV										
No	/	/			1.39*	1.00, 1.91	n/a	n/a	/	/
Yes					1.0 (ref)					
Ever taken HIV test										
No	/	/	/	/	/	/	n/a	n/a	0.65†	0.50, 0.85
Yes									1.0 (ref)	

[1]Significance: * $p<0.05$; † $p<0.01$.
[2]n/a means that the survey item was not asked of respondents in a district; - means that there were no observations for that category; / means that the variable was not significant in bivariate analysis and was not included in multivariable analysis.
[3]Adjusted incidence rate ratios (AIRRs) were presented because negative binomial regression was used to model the relationships between social and environmental factors and the numbers of clients per month. The AIRRs are interpreted as the estimated rate ratio comparing individuals in one category of an explanatory variable to the reference category, or for a one-unit increase in the value of a continuous explanatory variable, holding the values for all other variables constant. A rate is defined as the number of events that occur per unit time (i.e., the outcome, the numbers of clients per month); the rate at which events occur is called the incidence rate.

3.4 DISCUSSION

The findings from this analysis revealed several important social and environmental factors that may increase women's risk for HIV through having increased numbers of commercial sex clients per month. The most common predictors of higher rates of clients across multiple geographic regions were a reliance on sex work as sole income, younger age, and being single or cohabiting as compared to married. The environment in which women primarily solicited clients also played an important role in influencing client rates. The effect of this factor varied according to geographic region, with women soliciting in brothels and public places having higher rates of clients. On a population-level, measures of the numbers of clients per month displayed both geographic similarities and dissimilarities, highlighting both common elements of sex work and the importance of conducting geographically based analyses.

Globally, many women engage in sex work because they depend on the income, and the constrained economic conditions experienced by women in different settings have been shown to influence HIV risk related to sex work in many ways. For example, women's initiation into sex work and riskier sexual behaviour (e.g., agreeing to not use condoms with clients in exchange for higher income) is often due to a lack of other economic opportunities [Loza et al., 2010, Pyett and Warr 1999, Shannon et al., 2008a, Wojcicki and Malala 2001]. The results of the current study indicated that those who relied solely on sex work for income had rates of commercial sex clients that were 30%-70% higher than for women with other paid work. This indicates that FSWs in this study may compensate for their lack of additional income by having additional commercial sex clients. There are relatively limited employment opportunities for poorly educated women in India, and they tend to be low-paid and low-status [Blanchard et al., 2005, O'Neil et al., 2004, Orchard 2007, Rao et al., 2000, Shannon et al., 2008a]. Sex work can provide considerably greater income than other types of work (e.g., maidservant work or crafts) [Rao et al., 2000]; therefore, some women may choose not to seek employment other than sex work, and service increased numbers of clients per month to make a greater income. Women with other employment commitments may have reduced time to do sex work, and thus fewer clients. The significant negative association observed in one district between client volume and the amounts that women charge per sexual encounter, may indicate that FSWs in this district who charge less compensate by increasing client volume, even after adjusting for other factors that could affect the numbers of clients and sex work earnings (e.g., age). Yet, despite the importance of economic issues to sex work, little empirical research has been conducted to understand how sex work markets operate.

Work environment (i.e., places where women solicit clients, including homes, brothels or public places) also has frequently been identified as an important factor influencing women's risk for HIV [Buzdugan et al., 2009, Harcourt and Donovan 2005, Shannon et al., 2008a, Shannon et al., 2009a]. In contexts where sex work is criminalized or semi-criminalized, the places in which women solicit and service clients [Buzdugan et al., 2009] are often influenced by restrictive law enforcement policies. When indoor sex work spaces are illegal, women may be forced to solicit or service clients in public places in isolated areas, where they may have reduced access to harm reduction and health services, and increased risk for violence [Buzdugan et al., 2009, Harcourt and Donovan 2005, Shannon et al., 2008a, Shannon et al., 2009a]. The current analysis also identified work environment as an important factor in increasing FSWs' potential exposure to HIV through increased rates of clients, and in particular highlighted the importance of local geographic setting to work environment. In adjusted analysis, FSWs who solicited in brothels in two districts had significantly higher (50%-60%, $p<0.05$) rates of clients than home-based FSWs, while public places-based FSWs had 40% higher (p<0.01) rates than home-based FSWs in another district. FSWs who solicit clients mainly in their homes may be less socially vulnerable than those in other work environments; they are also less likely to report client-initiated violence or police harassment than brothel- and public places-based FSWs [Blanchard et al., 2005]. Brothel-based FSWs may have more clients to make up for the part of their earnings that must go toward pimps, madams or brothel owners [Buzdugan et al., 2009]. Previous research comparing public places-based and brothel-based FSWs with home-based FSWs found that home-based FSWs in southern India were less likely to be HIV-positive [Ramesh et al., 2008].

Younger age was associated with higher numbers of client partners in three districts (p<0.01). This may be partly due to the increased demand by clients seeking younger FSWs, or young FSWs' desire, need or opportunity to earn a larger income. Single and cohabiting FSWs reported more clients than married FSWs in several districts (70% and 60-80% more respectively, p<0.05). This is consistent with results from other studies suggesting that single FSWs were more likely to depend exclusively on sex work for their incomes in Karnataka [Ramesh et al., 2008], and to be HIV-positive in Karnataka [Ramesh et al., 2008] and in Pune, in Maharashtra state [Brahme et al., 2006]. As some married women practice sex work without their husband's knowledge, they may only be able to entertain clients during limited hours (e.g., while their husbands are away at work), or once they have accomplished their household duties, reducing their monthly client volume.

Features of social and environmental profiles of the districts also may help to explain population-level differences in the numbers of clients of FSWs. Belgaum, with the highest mean (and median) monthly number of clients, had a larger fraction of FSWs who solicited primarily in brothels and public places, who were also the FSWs with the highest monthly number of clients. Belgaum FSWs were paid substantially less money per sexual encounter compared with other districts, indicating that perhaps these women had increased monthly client volume to compensate. Bellary, with the second-highest mean/median number of monthly clients, had a much lower fraction of brothel/public-based FSWs, but a very high fraction of FSWs with sex work as their sole income. Shimoga, with the lowest mean/median monthly number of clients, had a high fraction of FSWs with sex work as sole income. However, Shimoga had a large fraction of married FSWs and home-based FSWs, who were those with the lowest monthly clients. Bangalore and Mysore, with the third- and fourth-ranked monthly clients, were the two most urban districts, and had high fractions of public places-based, younger FSWs and FSWs with shorter durations of sex work, but also charged higher prices per sexual encounter, and Bangalore had a high fraction of married FSWs. Mysore had a high fraction of literate FSWs, who in this district only, also had significantly lower monthly clients.

While previous studies have focused on describing features of the shape of the distribution of numbers of sex partners that could potentially influence HIV transmission and prevention [Hamilton et al., 2008, Jones and Handcock 2003], far fewer describe the factors that influence the numbers of partners; those that do frequently use population-based surveys from high-income countries [Brisson et al., 1999, Novak and Karlsson 2006]. Limitations in available data and study design issues (e.g., lack of individualized data) have hampered the ability to examine more upstream factors influencing numbers of partners of FSWs. While gaining an understanding of the determinants of the numbers of FSWs' clients is helpful for addressing program needs, this does not undermine the significant roles that other facets of interventions play in addressing risk to FSWs, such as improving condom use, community mobilization, community empowerment and education [Jana et al., 2004, Jana et al., 2006, Sarkar 2010], nor suggest that FSWs should limit their numbers of clients, as this would result in reductions of income on which they are frequently highly dependent.

Overall, a consistent pattern between average numbers of clients per month and condom use or HIV/STI prevalence at the population level was not observed, although results suggested that there may be a relationship between higher numbers of clients and having HIV or STIs (results not shown for the latter), which is supported by previous individual-level empirical analysis in southern India [Ramesh et al., 2008]. While having more clients may provide increased opportunities for HIV transmission and acquisition, the probability of transmission per sex act is also influenced by many factors, including the type of sex act performed (e.g., oral, anal or vaginal sex), condom effectiveness (e.g., proper use), the presence of STIs in either partner, and if either partner is HIV-positive [Boily et al., 2009, Choi et al., 2008]. It also is difficult to assess how current sexual activity is related to HIV status, since women may have become HIV-positive many years previously. Given the limitations of using any single factor to define individual-level risk for HIV infection, it would be worthwhile in future studies to identify and develop a description of risk for HIV transmission and acquisition, comprised of several risk factors, to better identify the most vulnerable FSWs.

There are several additional limitations to this analysis. The data are self-reported and therefore are susceptible to social desirability bias. Additionally, women were asked questions about events that occurred in the past and responses may therefore be affected by recall bias [Szklo and Nieto 1999]. To reduce the impact of recall bias, the variable ‘clients on the last day’ was used to derive the outcome, which was felt to be more accurately estimated by study participants than ‘clients on a typical day’. Both variables used to derive the outcome are dependent on when the respondent was interviewed and it is not known how the day on which respondents were asked would influence their response. A sensitivity analysis was conducted and the same analysis was repeated for six other measures of ‘clients per month’, revealing a strong correlation amongst the measures (Spearman’s correlation ranged from 0.62-0.97, $p<0.001$). The relationships between clients per month and social and environmental factors remained well-preserved across measures. The sample was not a population-based sample, since a sampling frame of all FSWs in southern India was not possible to construct due to the hidden nature of sex work; however, the cluster sampling design aimed to make the sample as representative as possible, and the sample size was large.

Findings from this analysis identified several social and environmental factors that were associated with having higher numbers of commercial sex partners of FSWs in southern India, including relying solely on sex work for income, as well as important interactions between geographic place of residence and sex work environment (i.e., soliciting clients in homes, brothels or public places). These results can be used to identify vulnerable sub-populations of FSWs who may be at higher risk for HIV infection. The numbers of clients per month varied geographically, which may reflect local underlying sexual networks that influence HIV prevalence, highlighting the importance of a geographically based analysis. Geography can be used as a proxy for underlying risk factors, helping target interventions toward areas with greater risk [Maas et al., 2007, Martens et al., 2002]. These results support the continued development of structural core group interventions that address common elements of sex work placing FSWs at higher risk for HIV, as well as geographically focused programs that account for local differences in sexual structure. Interventions should be tailored toward vulnerable sub-populations of FSWs to be more effective at influencing the HIV epidemic.

CHAPTER 4

THE VARIABILITY IN THE NUMBERS AND TYPES OF SEX PARTNERS OF FEMALE SEX WORKERS AND THE HIV EPIDEMIC IN SOUTHERN INDIA

4.1 INTRODUCTION

In southern India, the HIV epidemic is thought to be driven primarily by heterosexual transmission [Arora et al., 2004]. Commercial sex partnerships have been shown to play an important role in HIV transmission dynamics in this setting [Vickerman et al., 2010]. Theoretically, in many settings, the establishment and spread of HIV depends on a small group of individuals with high rates of partner change, known as core groups (e.g., female sex workers (FSWs)) who disproportionately transmit infections within and beyond their sub-population depending on their level of sexual linkage with the wider population (e.g., through partnerships with clients, who have sex partners from both FSW and general populations) [Anderson and May 1991, Anderson et al., 1991, Boily and Anderson 1991].

Women who engage in sex work in southern India are highly vulnerable to becoming HIV positive and/or becoming infected with sexually transmitted infections (STIs) during their lifetimes [Beattie et al., 2010, Blanchard et al., 2005, Blanchard et al., 2007, HIV Sentinel Surveillance and HIV Estimation in India 2007 A Technical Brief 2008, Ramesh et al., 2008, Ramesh et al., 2010]. The HIV epidemic among FSWs is highly geographically heterogeneous within and across states in southern India [HIV fact sheets: based on HIV sentinel surveillance data in India, 2003-2006 2007, HIV Sentinel Surveillance and HIV Estimation in India 2007 A Technical Brief 2008]. In Karnataka state, one of six states in India where HIV prevalence has exceeded 1% in the general population in recent years, HIV prevalence among FSWs was found to be many times larger and to vary from 9.6% to 33.9% in 2005 in selected districts (sub-state administrative areas) where a large-scale, core group HIV prevention intervention (the Avahan AIDS Initiative) has been ongoing since 2003 [Ramesh et al., 2008].

However, to date, the large geographic differences in HIV prevalence across FSW populations in southern India remain largely unexplained. Heterogeneity observed in the sexual structure within and across FSWs and their partners has recently been hypothesized to play an important role in the spread of HIV at a population level among FSWs and general populations [Blanchard et al., 2007, Blanchard et al., 2008b]. Theoretical studies have indicated that the level of clustering in the distribution of the numbers of clients per FSW (i.e., when the numbers of clients are distributed unequally across a FSWs rather than uniformly) and whether FSWs visit the same clients repeatedly (instead of new ones) can influence overall prevalence of STIs, such as herpes simplex-2 virus and gonorrhoea [Ghani and Aral 2005]. Moreover, heterogeneity in the sexual structure of FSWs could have important implications for prevention on a population level. For example, if a small fraction of the FSW population is responsible for the majority of the commercial sex partnerships (e.g., clustered), then identifying this sub-population and tailoring interventions toward members could have a more substantial impact than an intervention targeted toward the general FSW population [Blanchard et al., 2008a]. This hypothesis is an extension of core group theory, which has extensively developed the hypothesis that interventions tailored for core groups could have positive impacts on reducing HIV rates in general populations. Despite this, heterogeneity in the sexual structure of FSWs and the relative importance of specific features of sexual structure to the spread of HIV on a population level has not been examined in detail.

The current analysis therefore investigated the heterogeneity in the sexual structure of FSWs and their male sex partners within and across three districts in Karnataka State, southern India. Using mathematical modelling techniques, this analysis aimed to demonstrate how sexual structure influenced HIV prevalence within districts and identified specific individual parameters that were important in explaining the differences in HIV prevalence between the three districts. Sexual structure parameters of interest within districts included measures of variability in the numbers of clients of FSWs (e.g., Gini coefficients, variance), and within and across districts included the numbers of clients of FSWs and numbers of visits by clients to FSWs, the frequency of sex acts with repeat and occasional clients, the fraction of repeat clients and repeat FSWs, the duration of the repeat client and repeat FSW relationship, FSW population size, and condom use with different sex partners.

4.2 METHODS

Data collection

A secondary analysis of data gathered through two primary data collection efforts was performed. The data sources included the Integrated Biological and Behavioural Assessments (IBBA) and the Special Behavioural Surveys (SBS), collected in urban areas of three districts in Karnataka state (Bangalore Urban, Belgaum and Bellary) as part of the Avahan AIDS Initiative [Avahan, the India AIDS Initiative - the Business of HIV prevention at Scale 2008]. Both surveys collected information on demographics, sexual behaviour and sex work environment, whereas biological samples (HIV and STIs) were only collected as part of the IBBA. A time-location cluster procedure was used to sample FSWs in the IBBA as described in Ramesh et al, 2008 [Ramesh et al., 2008]; similar methods were used for the SBS. The IBBA was conducted in

2004-05 and 2007-08 for FSWs and 2008 for clients, whereas the SBS was conducted in 2005-06 only for FSWs. Both surveys were administered as face-to-face interviews. The surveys and their protocols were approved by the Government of India's Health Ministry Screening Committee and the respective Canadian university research ethics boards.

Analysis

First, the sexual structure of FSWs and their male sex partners (including commercial clients and intimate partners) was described within and across each district using the IBBA (2005 and 2007) and SBS (2005) data. Measures of centrality (e.g., mean, median, quartiles) and variability (e.g., variance, skewness, Gini coefficient) were calculated from the numbers of clients per month reported by FSWs from multiplying responses to the survey item "How many clients did you entertain on your last working day?" by responses to "How many days in a typical month do you entertain clients?". The Gini coefficient was calculated for each distribution of the numbers of clients of FSWs per month and Lorenz curves were produced (as detailed in Appendix 3) to characterize variability in the partner distributions within districts and compare across districts. A higher Gini coefficient and a more skewed Lorenz curve indicate greater heterogeneity in the distribution [Blanchard et al., 2007, Blanchard et al., 2008a, Wagstaff et al., 1991]. Other features of sexual structure, including sex partnering patterns between FSWs and their sex partners (occasional and repeat clients and intimate partners) in each district were described to compare across districts.

Mathematical model description and baseline assumptions

A deterministic compartmental mathematical model of HIV transmission between FSWs and their male partners was developed using self-reported data from FSWs and clients. The model was fitted to HIV prevalence data collected in biological samples as part of the IBBA. The FSW population was first stratified into compartments representing sub-populations of FSWs with different types of sex partnerships (those having both intimate [i.e., non-commercial] and commercial sex partners versus those having only commercial sex partners) (Figure 4.1a). FSW model compartments were further stratified into sub-populations according to: place of solicitation (home-based, brothel-based or public places-based); sex work as sole income (no other paid work or other paid work); and marital status (married or unmarried). These factors were strongly associated with numbers of clients of FSWs in previous analysis [Deering et al., 2010b]. This resulted in 12 different compartments of FSWs who had intimate partners and commercial clients and 6 compartments of FSWs who only had commercial clients (Figure 4.1b). Males were stratified into two compartments representing sub-populations of clients who either had or did not have FSWs as intimate partners (Figure 4.1a). All males who did not have intimate FSW partners were assumed to be clients, while a fraction of males (estimated from data) who had intimate partners were also assumed to be clients of other FSWs. A fraction of commercial sex partnerships from each sub-population of FSWs and clients were assumed to be repeat and a fraction were assumed to be occasional partnerships. FSWs and clients were assumed to remain in these sub-populations for the entire time they did sex work/were clients of FSWs. Each sub-population was then stratified into compartments representing different stages of infection (i.e., susceptible, three stages of infection and AIDS). Individuals entered the population as susceptible, and then progressed through the stages of infection once infected with

HIV. Consistent with previous studies on HIV transmission dynamics in this setting and the natural history of HIV infection [Boily et al., 2008, Boily 2009, Deering et al., 2008, Hollingsworth et al., 2008, Pickles et al., 2010, Vickerman et al., 2010, Wawer et al., 2005, Williams et al., 2006], individuals infected with HIV were assumed to experience an initial short acute phase (5 months) of high infectivity, followed by a long low-infectivity phase (6.4 years), a pre-AIDS phase of increased infectivity (one year) and an AIDS phase (one year). Individuals with AIDS were assumed to cease sexual activity due to illness (Figure 4.1c).

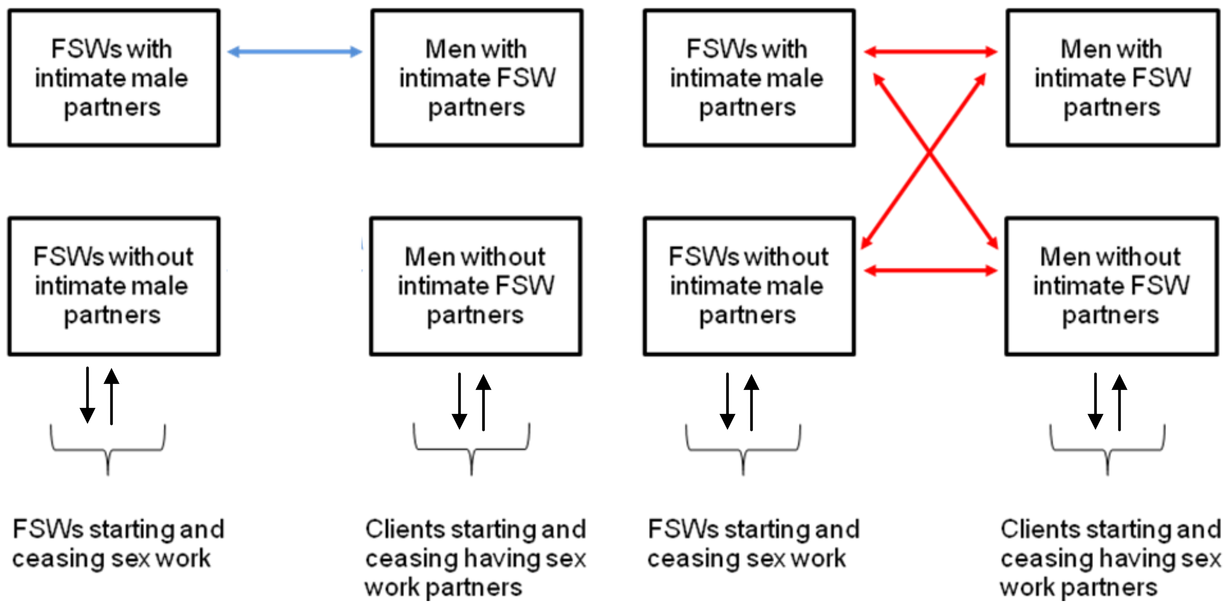
The model represented a sexually active population, assumed to grow at a rate of 1.8% per year, as reported in Indian census data. The force of infection depended on the probability of HIV transmission per partnership (Equation 4.1), the infection stage, and the average numbers of each type of sex partner (see Appendix 3). The probability of HIV transmission varied according to the type of partnership (occasional client, repeat client and intimate partner) via the frequency of sex acts and condom use. The transmission probabilities per partnerships (β) increased with higher numbers of sex acts (N) according the Bernouilli process described by Equation 4.1, where *p* is the probability of transmission of HIV per sex act (see Appendix 3 for details).

$$\beta = 1 - (1 - p)^N \qquad (4.1)$$

The model was comprised of a series of non-linear ordinary differential equations and coded using Berkeley Madonna version 8.3.18 (see Appendix 3 for details).

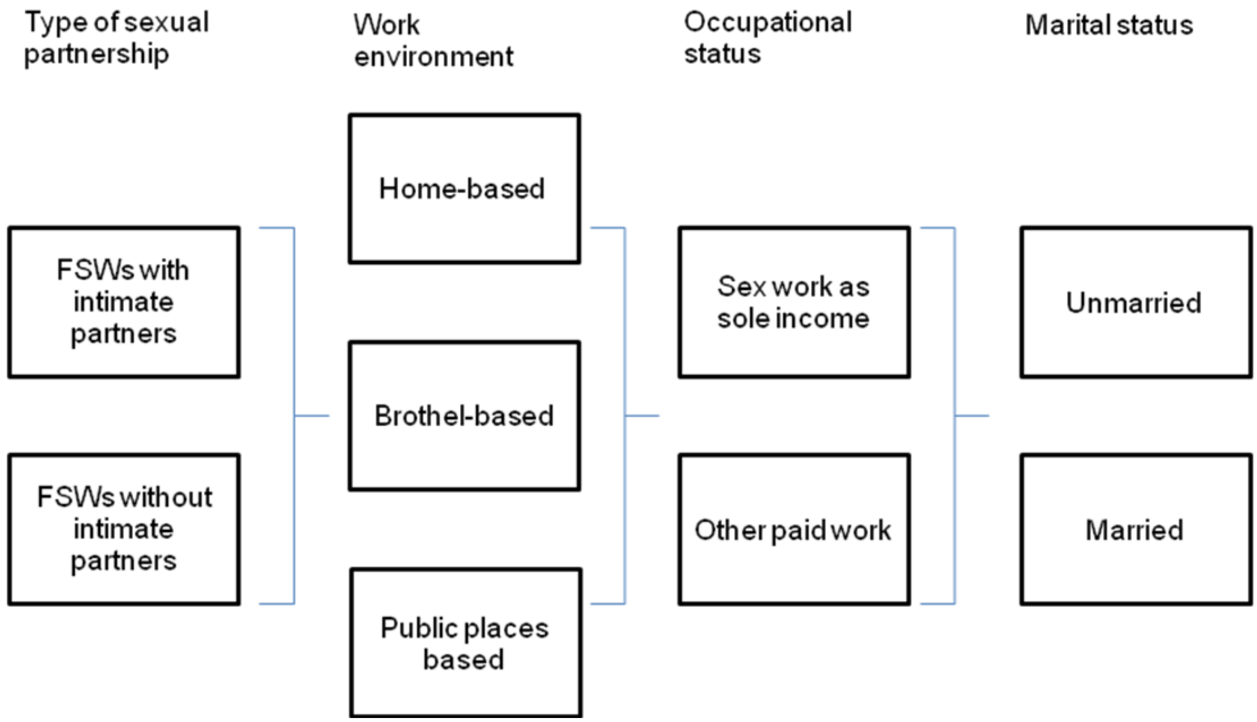
Figure 4.1: Outlines and descriptions of how the mathematical model was compartmentalized to represent HIV transmission dynamics in Karnataka state, India, including:

(a) Outline of the main aspects of sexual structure and population movements of female sex workers and their male sex partners.[1]



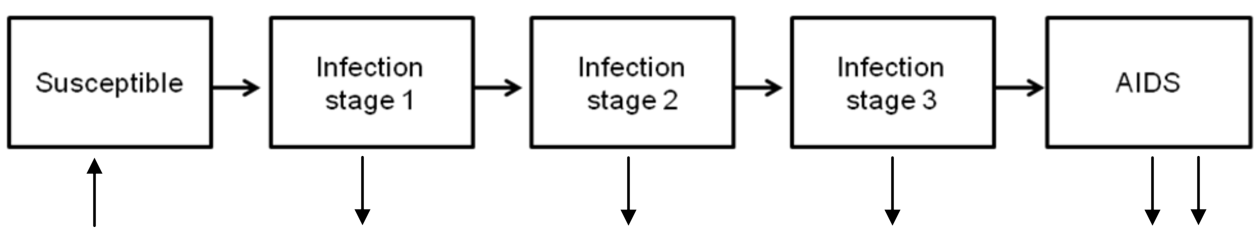
[1]Potential routes of transmission of HIV are demonstrated with double-headed arrows. Blue double-headed arrows represent intimate (i.e., longer-term, with many sex acts per partnership) partnerships, while red double-headed arrows represent commercial partnerships (i.e., shorter-term, with few sex acts per partnership). FSWs and clients engage in commercial sex for a fixed duration of time (e.g., average duration of sex work and client behaviour) before returning to the general population and being replaced by a proportionate number of FSWs and clients from the general population (black single-headed arrows). All new FSWs and clients are assumed to be HIV-negative. Age was not considered in this model.

(b) Outline of the main stratifying factors that divide the overall population of FSWs into sub-populations.[2]



[2] There are 12 compartments for FSWs with intimate partners and 6 compartments for FSWs without intimate partners, as there are no FSWs without intimate partners who are married

(c) Outline of the infection dynamics and stages of infection for HIV transmission.[3]



[3] New susceptible individuals move into the population. Individuals move out of the population through death from natural causes (in each stage of infection) as well as AIDS deaths (in the AIDS compartment only). HIV infection was modelled with a high viraemia phases during initial infection (Stage 1) and in the infection stage occurring shortly before developing AIDS (Stage 3), with a longer stage with lower infectiousness between these two stages (Stage 2). Infected individuals progress from primary to asymptomatic to pre-AIDS stages at rates from the literature.

Plan of analysis

As a preliminary step, district-specific sexual structure data were used to fit the model to observed HIV prevalence in Belgaum (baseline district), the district with the highest HIV prevalence, while biological parameters were estimated from the literature. The overall analysis was conducted in three main steps to identify the specific sexual structure parameters that had the largest impact on HIV prevalence. Each step included a univariate sensitivity analysis (see Figure 4.2 for a summary), as follows:

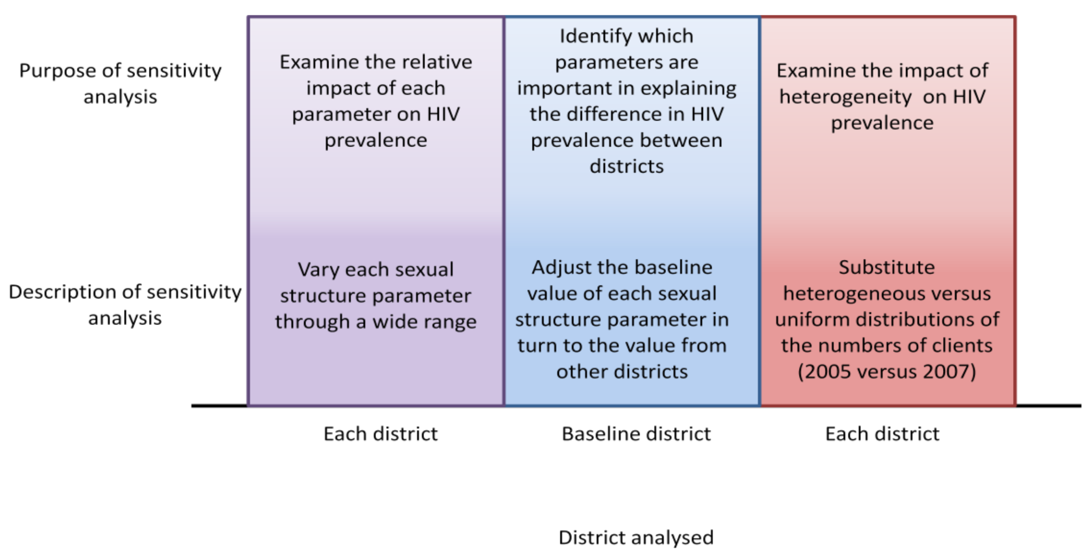
- First, to examine the relative impact of each sexual structure parameter on HIV prevalence, within the baseline district, each parameter was varied over a wide range (half to double the baseline value). Table A1.1 describes the range of values used for each parameter investigated. As a complementary analysis, results were validated using a model fit identified for each of the two other districts in the second sensitivity analysis.
- Second, the district-specific sexual structure parameters that were important in explaining the differences in HIV prevalence between the three districts were identified. This was done by starting with the baseline district and then **individually substituting**, in turn, the value of each sexual structure parameter to the value from each of the other two districts. These parameters were then **substituted** together to identify the **combination (set)** of parameters that fit the model to observed HIV prevalence in each of the two districts.
- Third, the influence of different sexual activity distributions (numbers of clients of FSWs per month) on HIV prevalence was assessed within each district (using the model fit for each district as above). This was assessed by comparing the heterogeneous distribution (i.e., where sub-populations are assigned specific sub-population means as in previous steps) with a uniform distribution (i.e., all sub-populations are assigned the same overall

population mean) from both 2005 and 2007. Figures A2.1a-A2.1f (Appendix 2) describe the uniform and heterogeneous distributions from 2005 and 2007 in each district.

In all sensitivity analyses, the model included a ‘balancing activity constraint’, such that the total number of partnerships that FSWs had with males must equal the number of partnerships that males had with FSWs (Equation 4.2 for clients). Thus, varying the value of one sexual structure parameter often influenced the value of another parameter, since the parameters were dependent on one another. **As a rule**, client/intimate partner population size was always allowed to vary to keep the number of partnerships the same. In addition, varying individual sexual structure parameters often influenced the total number of partnerships, which could either increase or decrease depending on the parameter varied.

$$PopSize_{Client} * M_{Client} = PopSize_{FSW} * M_{FSW} \qquad (4.2)$$

Figure 4.2: Summary of sensitivity analyses conducted to understand the impact of sexual structure on HIV prevalence in Karnataka state, India.



Model parameters for model fitting in Belgaum

Table 4.1 presents the biological, demographic and behavioural parameters used for model fitting to HIV prevalence in Belgaum district. The population size of FSWs in Belgaum in 2005 was estimated to be 2,000 using FSW enumeration data. The male client population size in 2005 (135,721) was estimated by triangulation using the size of the FSW population, the reported total numbers of clients of FSWs per year (M_{FSW}) and numbers of visits by clients to FSWs per year (M_{Client}). This was done to satisfy the balancing activity constraint (Equation 4.2).

Overall, just over half (52.4%) FSWs reported having a current intimate (i.e., non-commercial) partner, with an average of 1.4 different intimate partners in the last year. The average duration of the most recent three intimate partnerships was 9.5 years and there was an estimated average of 92 sex acts per year within intimate partnerships. The intimate partner population size was estimated to be 1,467 (based on FSW population size and the numbers of intimate partners of FSWs, assuming that male intimate partners had only one intimate FSW partner per sexually active lifetime). The fraction of intimate partners who were also clients of FSWs was estimated (6.5%). FSWs reported an average duration of sex work of 9.6 years and, on average, clients reported visiting FSWs for 8.5 years. FSWs reported that 35% of their clients (out of the last 10) were repeat clients and there was average of 54 sex acts per year in each repeat partnership. The heterogeneous distribution in Belgaum was used for the baseline (Table 4.1). The average duration of the repeat client relationships was 2.5 years and FSWs were assumed to have 3.5 new repeat clients per 2.5 years, or just over 1 per year on average (See Appendix 3 for calculations). The remainder of the clients were assumed to be occasional. The numbers of intimate or commercial sex partners per male in the model over time was determined by population sizes and the constant numbers of male (commercial or intimate) partners per FSW over time. This is a restriction required to satisfy the balancing activity constraint (Equation 4.2).

Based on estimates regarding condom use from the start of the epidemic, consistent condom use (CCU) (i.e., ‘always’ compared to ‘frequently/sometimes/never’) with occasional clients was assumed to increase linearly from approximately 10% at the start of the epidemic to 35.4% in 2002. CCU with occasional clients was then assumed to increase linearly to 80.7% in 2005 and 89.1% in 2008 (Figure A2.1, Appendix 2) [Bradley et al., 2010, Pickles et al., 2010]. CCU with repeat clients was assumed to be 14% lower than with occasional clients and 62% lower with intimate partners over time (Table 4.1).

Table 4.1: Biological, demographic and behavioural parameters for the baseline model (Belgaum district) of HIV transmission among female sex workers and their male sex partners.[1,2]

Type of parameter	Description of parameter	Values	Reference
Biological			
HIV Transmission probability per sex act	Male to female		[Boily et al., 2009, Wawer et al., 2005]
	Stage 1 (acute infectious)	4.5-18.8 times Stage 2	
	Stage 2 (latent)	0.0006-0.0011	
	Stage 3 (increasing infectious)	4.5-11.9 times Stage 2	
	Female to male		
	Stage 1 (acute infectious)	4.5-18.8 times Stage 2	
	Stage 2 (latent)	0.0001-0.0014	
	Stage 3 (increasing infectious)	4.5-11.9 times Stage 2	
HIV duration of infectiousness	Stage 1 (acute infectious)	0.33-0.5	[Grover and Shivraj 2004, Kumarasamy et al., 2003]
	Stage 2 (latent)	5.33-7.54	
	Stage 3 (increasing infectious)	0.50-1.50	
	AIDS	1.00	
Condom efficacy	Condom efficacy for HIV transmission per sex act	80%-95%	[Pinkerton and Abramson 1997, Pinkerton et al., 1998]
Demographic			
2005 total population sizes	Female sex workers	2,000	Avahan estimates
	Male clients total	135,721	determined by number of FSW-client partnerships
	Male intimate partners of FSWs	1,467	determined by number of FSW-intimate partner partnerships
Type of partner – female sex workers	Fraction of FSWs with an intimate partner	52.4% (47.8%-61.2%)	IBBA
	Fraction of clients of last 10 who are repeat	35% (32%-39%)	IBBA
	Fraction of clients of last 10 who are occasional	65% (61%-68%)	IBBA

Type of parameter	Description of parameter	Values		Reference
Behavioural				
Distribution of female sex worker population sizes by all categories	Fraction of FSWs who are:			
	Home, Sex work sole, Single	0.084	0.110	IBBA
	Home, Sex work sole, Married	0.009	0	
	Home, Other paid work, Single	0.188	0.124	
	Home, Other paid work, Married	0.062	0	
	Brothel, Sex work sole, Single	0.112	0.288	
	Brothel, Sex work sole, Married	0.452	0	
	Brothel, Other paid work, Single	0.050	0.145	
	Brothel, Other paid work, Married	0.029	0	
	Public, Sex work sole, Single	0.091	0.110	
	Public, Sex work sole, Married	0.028	0	
	Public, Other paid work, Single	0.181	0.224	
	Public, Other paid work, Married	0.112	0	
Sexual behaviour of FSWs, with their intimate partners	Number of current different intimate partners	1.4 (1.2-1.6)	n/a	IBBA
	Number of times had sex with most recent intimate partner per year	91.5 (67.6-114.9)	n/a	determined by number of times had sex per week
	Duration of most recent intimate relationship (years)	9.5 (8.0-11.0)	n/a	IBBA
Sexual behaviour of FSWs, with their clients	Average numbers of clients of FSWs per month	56.0 (49.2-68.9)		IBBA
		55.3 (42.9-67.8)	58.9 (48.7-69.1)	IBBA
	Numbers of clients of FSWs per year who are:			
	Home, Sex work sole, Single	39	66	IBBA
	Home, Sex work sole, Married	48	0	
	Home, Other paid work, Single	44	36	
	Home, Other paid work, Married	32	0	
	Brothel, Sex work sole, Single	118	85	
	Brothel, Sex work sole, Married	36	0	
	Brothel, Other paid work, Single	97	50	
	Brothel, Other paid work, Married	57	43	
	Public, Sex work sole, Single	83	0	
	Public, Sex work sole, Married	43	27	
	Public, Other paid work, Single	47	0	
	Public, Other paid work, Married	28	39	
	Number of sex acts per occasional client	1		assumed
	Number of sex acts with repeat clients per year[3]	49.6 (40.8-58.4)		SBS
	Duration of repeat client relationship (years)	2.5		SBS
	Average duration in sex work (years)	9.6 (8.3-10.9)		IBBA

Type of parameter	Description of parameter	Values	Reference
Sexual behaviour of clients, with FSWs	Numbers of FSWs per year (2005):	6.5	see Appendix 3 for calculation
	Numbers of FSWs over time	Determined by FSWs	
	Duration of being a client (years)	8.5 (7.4-9.6)	IBBA
Sexual behaviour of intimate partners, with FSWs	Fraction of intimate partners of FSWs with other FSW partners (e.g., clients)	6.5% (0.6-16.5%)	SBS
	Numbers of FSWs per year over time	Determined by FSWs	
	Duration of being an intimate partner of FSWs (years)	9.5 (8.0-11.0)	(same as for FSWs)
Condom use	Fraction of sex acts with occasional clients where condoms are always used		
	Start of HIV epidemic (1976)	10%	
	First time point (2002)	35.4%	
	Second time point (2005)	80.7%	[Bradley et al., 2010, Pickles et al., 2010]
	Third time point (2007)	89.1%	
	Co-factor for fraction of sex acts with repeat clients where condoms are always used	0.86	IBBA
	Co-factor for fraction of sex acts with intimate partners where condoms are always used	0.38	IBBA
Dates	Under H1/(Pickles et al 2010)		
	Start of HIV epidemic	1976-1985	
	First time point	2002	
	Second time point	2005	
	Third time point	2008	[Pickles et al., 2010]

[1] If only a range was given (95% confidence intervals), the model parameter used was the middle of the range, except in the case of transmission probabilities, which were at the high end of the range.
[2] Ranges (95% confidence intervals) were able to be calculated for some parameters which were directly estimated or derived from survey questions, but others were estimated using direct calculations (and hence do not have 95% confidence intervals).
[3] To fit the model to observed HIV prevalence, the number of sex acts with repeat clients was slightly higher than the average but within-range of the 95% confidence intervals (54 sex acts per year).

4.3 RESULTS

Sexual structure within and across districts

There were considerable differences in sexual structure within and across the three districts (Tables 4.2a and 4.2b). Belgaum had the highest average overall numbers of clients per month in 2005 (56.0), while Bangalore had the lowest (34.4) (Table 4.2a). Average numbers of clients were similar between 2005 and 2007 for Belgaum and Bangalore but increased by over 50% in Bellary (46.4 clients to 72.5 clients). As the average numbers of clients per month increased across districts, HIV prevalence across these three districts also increased. As the Gini coefficient for the distribution of the numbers of clients per month increased across districts, skewness and variance in the distributions also approximately increased. These measures did not appear to be associated with HIV prevalence in FSWs in these few districts. HIV prevalence was highest in Belgaum (2005), which had a middle-range Gini coefficient, variability and skewness. HIV prevalence was lowest in Bangalore (2007), which also had a middle-range Gini but relatively low variance and high skewness. The Gini coefficient was highest in Bellary in both 2005 and 2007 (0.54 and 0.53), indicating the most unequal distribution and highest clustering in this district. The Gini was lowest in Bangalore in 2005 (0.39) and Belgaum in 2007 (0.37), indicating a more uniform distribution of the numbers of clients. Lorenz curves are shown in Figure A2.3 in Appendix 2.

In 2005, the majority of FSWs in all districts reported a mix of occasional and repeat clients (Table 4.2b). In Bellary, Belgaum and Bangalore, 2.5%, 3.4% and 11.9% ($p<0.001$) of FSWs, respectively, reported only having occasional clients, while 9.2%, 0.2% and 2.2% ($p<0.001$) reported only having repeat clients (results not shown). In Bellary, more women reported having a higher fraction of repeat than occasional clients (45% versus 35% and 29% in

Belgaum and Bangalore; $p<0.001$). The duration and number of sex acts per repeat client partnership were highest in Belgaum and lowest in Bangalore and Bellary. Bangalore had the most FSWs with an intimate partner and the highest number of sex acts with these partners. CCU was highest with occasional and repeat clients in Belgaum ($p<0.001$ across districts). CCU was highest with intimate partners in Bellary and Belgaum and much lower in Bangalore (45.7%, 41.6% and 12.8%; $p<0.001$).

Table 4.2: Selected characteristics of the sexual structure of female sex workers and their male partners in Karnataka state, India, including:

(a) Measures of centrality and variability for the number of clients of female sex workers, as well as HIV prevalence in female sex workers and clients.

District	Female sex workers														Clients (2008 only)	
	Year	N	Mean numbers of clients per month[95% CI]	Variance	Skew-ness	Number of clients per month by percentiles					Range		Gini coeffi-cient	HIV positive %[95% CI]	N	HIV positive % [95% CI]
						10th	25th	50th	75th	90th	Min	Max				
Belgaum	2005	376	56.0 [48.1-63.9]	3041.0	2.4	12	20	40	75	104	1	750	0.45	33.9 [27.6-40.2]	412	6.2 [3.6-8.8]
	2007	366	53.5 [49.4-57.5]	1453.0	1.6	15	25	44	72	100	4	275	0.37	27.3 [22.2-32.5]		
Bellary	2005	413	46.4 [36.8-56.0]	3819.0	3.5	6	10	30	60	104	2	750	0.54	15.6 [11.1-20.0]	430	6.0 [2.6-9.5]
	2007	385	72.5 [54.1-90.8]	8546.0	3.1	15	24	44	75	144	4	700	0.53	14.1 [10.5-17.8]		
Bangalore	2005	649	34.4 [31.3-37.4]	735.2	2.5	10	15	30	44	64	4	270	0.39	12.7 [8.6-16.7]	705	2.4 [0.9-3.9]
	2007	666	33.9 [30.9-36.9]	948.6	4.0	8	15	28	40	60	1	375	0.41	8.0 [5.3-10.7]		

(b) Patterns of sexual contact between female sex workers and their male partners.

			District			p-value	Source
			Belgaum	Bellary	Bangalore		
Sexual structure	Numbers of clients per FSW per month	Mean	56	46[2]	34[3]	<0.001	IBBA
	Number of FSWs per client per six months	Mean	3.6	4.2	4.7[3]	0.012	IBBA
	Fraction of repeat clients (of FSWs)	Mean	35.0%	44.0%	29.0%	<0.001	IBBA
	Fraction of repeat FSWs (of clients)	%	0.17	0.19	0.22	0.091	IBBA
	Duration of repeat client partnership (months)	Mean					
	Most recent		33.6	28.8	16.8[3]	<0.001	SBS
	2nd most recent		27.6	24.0	15.6	0.008	
	3rd most recent		30.0	19.2	20.4	0.187	
	Overall		30.4	24.0[2]	18.0		
	Numbers of sex acts with repeat clients (per month)	Mean					
	Most recent		4.5	3.8	4.4	0.532	SBS
	2nd most recent		4.1	2.1	3.4	0.001	
	3rd most recent		3.8	2.0	3.1	0.026	
	Overall		4.1	2.6[2]	3.6[3]		
	Number of sex acts with occasional clients (per client)	Mean	n/a	n/a	n/a	n/a	n/a
	Duration of sex work (years)	Mean	9.7	8.7	3.9[3]	<0.001	IBBA
	Duration of being a client (years)	Mean	8.5	8.5	9.1	0.092	IBBA
	Fraction of FSWs with a main intimate partner	%	52.4%	64.3%	69.0%	<0.001	IBBA
	Number of sex acts with main intimate partner (per month)	Mean	7.5	8.3	8.8	0.022	IBBA
	Number of intimate partners (over lifetime)	Mean	1.4	1.3	1.8	0.128	IBBA
Condom use	Always use condoms w/ main intimate partner[1]	% (N)	41.6%	45.7%	12.8%	<0.001	IBBA
	Always use condoms with repeat clients[1]	% (N)	78.6%	67.9%	60.3%	<0.001	IBBA
	Always use condoms with occasional clients[1]	% (N)	90.9%	72.8%	78.0%	<0.001	IBBA

[1]Always is equal to 100% of the time, and is compared with responses including often/sometimes/never
[2]These parameters were used to fit the model to HIV prevalence in Bellary
[3]These parameters (in addition to FSW size) were used to fit the model to HIV prevalence in Bangalore

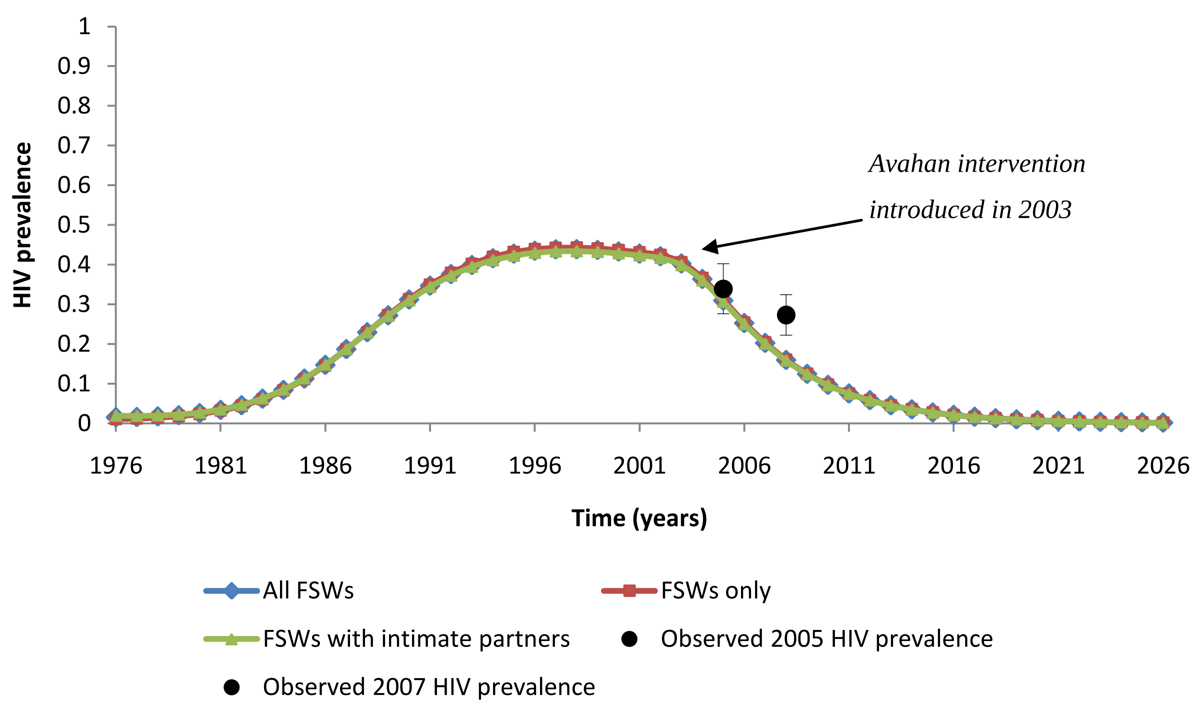
Model results

Baseline HIV transmission

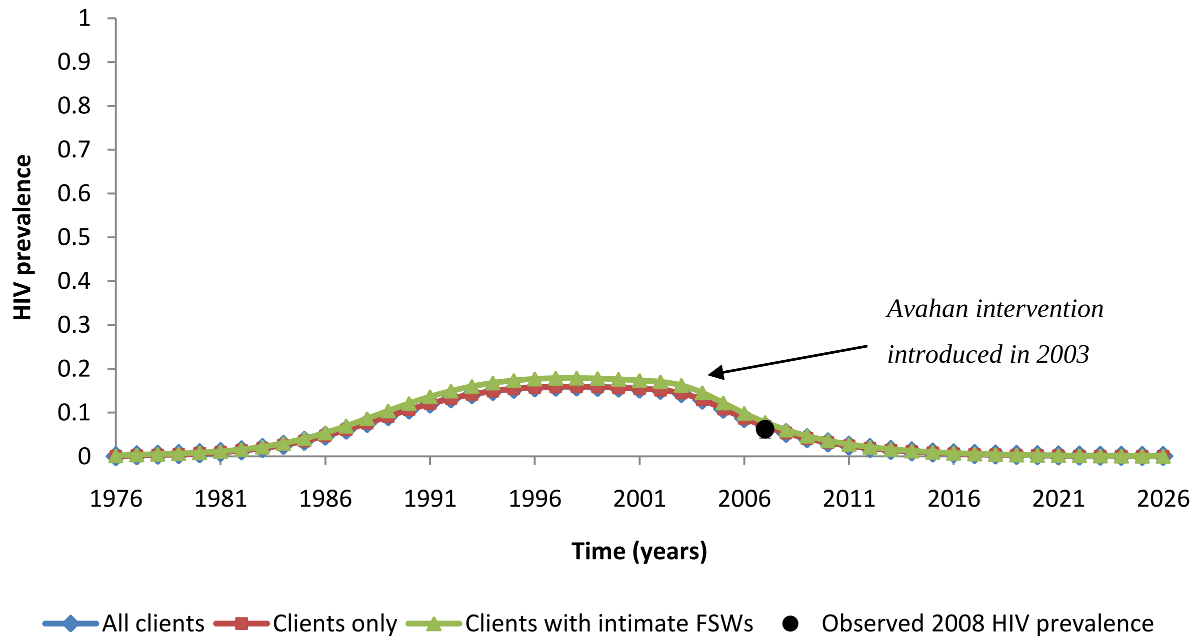
Figures 4.3a and 4.3b show HIV prevalence over time for FSWs and clients respectively, using baseline data from Belgaum district. Model HIV prevalence among FSWs (31.0%) fit well to the observed data in 2005, though it was slightly lower (20.3%) compared to observed data in 2007. This could indicate that self-reported or reconstructed increases in CCU used in the model are too high (perhaps due to social desirability bias) after 2005 among FSWs, or be because of changes in the FSW sample population from 2005 to 2007 (not accounted for in the model). A slightly different set of model parameters also may have produced HIV prevalence within the observed range of values in 2007. Model HIV prevalence among clients in 2008 (6.9%) was within-range of observed prevalence.

Figure 4.3: Baseline modelled HIV prevalence in Belgaum (baseline district) among:

(a) Female sex workers.



(b) Clients of female sex workers.



Sensitivity analysis

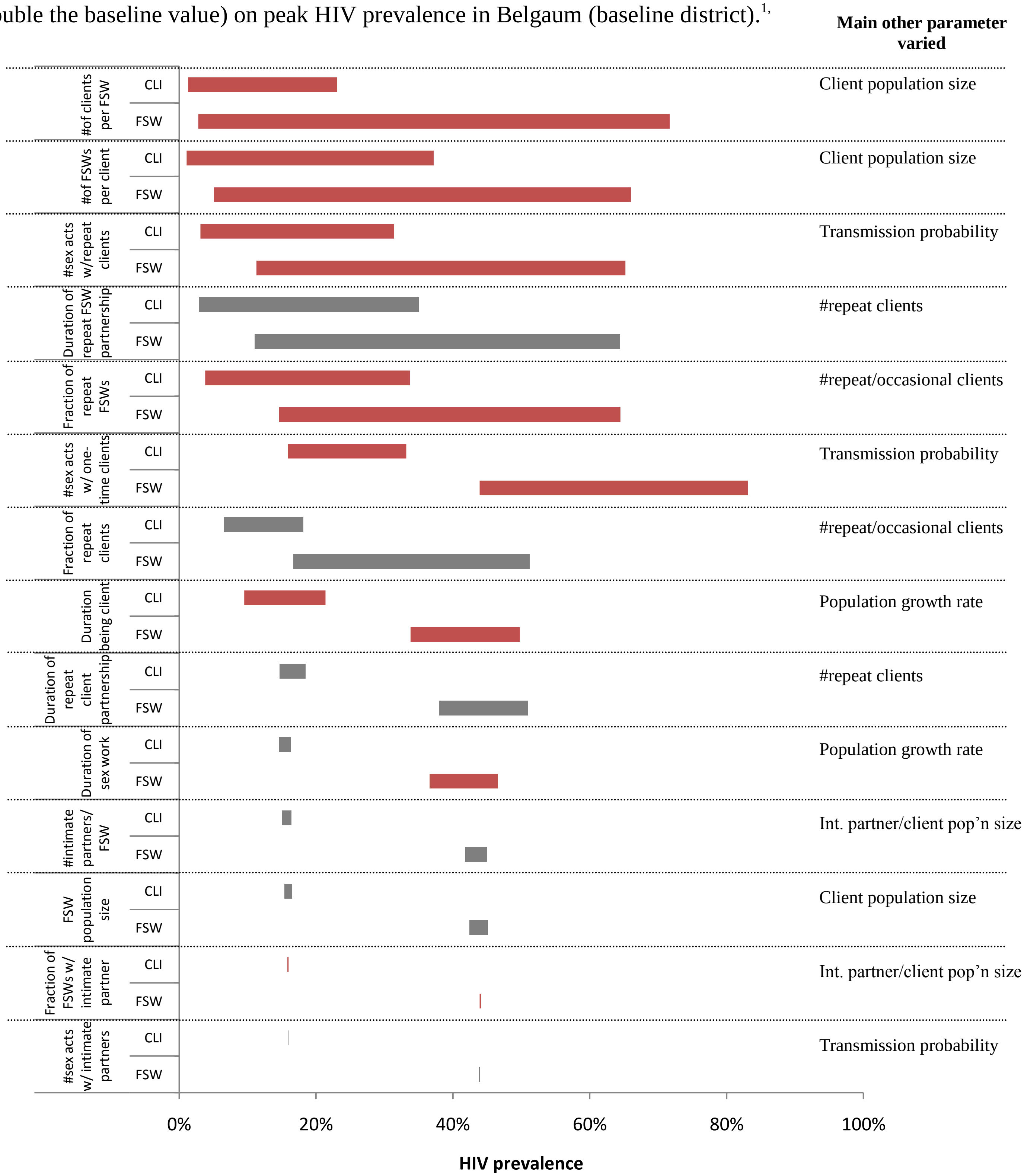
- First: influence of sexual structure parameters on HIV prevalence

Figure 4.4 displays results from the first sensitivity analysis. Results indicated that the largest variability/change in peak FSW HIV prevalence was observed when varying Belgaum's average number of clients per FSW (i.e., by varying all sub-population means together from half-to-double the baseline value), indicating the high sensitivity of HIV prevalence to this parameter (Figure 4.4). Peak HIV prevalence among FSWs in Belgaum using the baseline parameters occurred in 1999. The FSW and client HIV peak prevalence was much higher (FSWs: 71.7%; clients: 23.1%) and occurred sooner (1990) with the maximum value for the number of clients (double the baseline values across sub-populations) compared to the lowest value (half the baseline values across sub-populations) (HIV prevalence in FSWs: 2.8%; clients: 1.3%). To satisfy the balancing activity constraint (Equation 4.2), an *increase* (or decrease) in the number of clients per FSW resulted in a corresponding *increase* (or decrease) in client population size. The larger population size caused the infection to grow more slowly and peak later, but resulted in increased prevalence due to higher numbers of sexual contacts. Peak HIV prevalence also increased substantially when increasing the numbers of FSWs visited by clients, since *increasing* (decreasing) the numbers of FSWs visited by clients *decreased* (increased) client population size. The smaller population size and increased sexual contacts caused the infection to peak earlier. Additionally, HIV prevalence was positively correlated with the number of sex acts per repeat client and per occasional client, despite the small absolute changes in the latter (from 1 to 3 acts).

Interestingly, HIV prevalence was strongly negatively correlated with a longer average duration of the repeat partnership that clients reported having with FSWs. This is because in these simulations, the number of repeat FSWs visited by clients decreased as the duration of the repeat partnership increased (from 1 to 0.25 repeat FSW per year) and the numbers of occasional clients remained the same (see Appendix 3 and Table A1.2 in Appendix 1 for all calculations). Given the high numbers of sex acts within repeat client partnerships and the relatively low average numbers of client visits to (all) FSWs, this decreased infection rates substantially. HIV prevalence was positively correlated with the fraction of FSWs visited repeatedly by clients, since increasing this parameter increased the numbers of repeat FSWs visited by clients (from 0.25 to 1 FSWs per year). In contrast, HIV prevalence was negatively correlated with a higher fraction of clients seen repeatedly by FSWs, since increasing this parameter increased the number of repeat clients of FSWs (from 1 to 4 repeat clients per year) and thus substantially decreased the numbers of occasional clients of FSWs (from 567-205 occasional clients per year). HIV prevalence was also negatively correlated with a longer duration of the repeat partnership that FSWs reported having with clients, though the impact on HIV prevalence was relatively small. In these simulations, the numbers of repeat clients decreased (from 4 to 1 repeat client per year) when increasing the duration of the partnership.

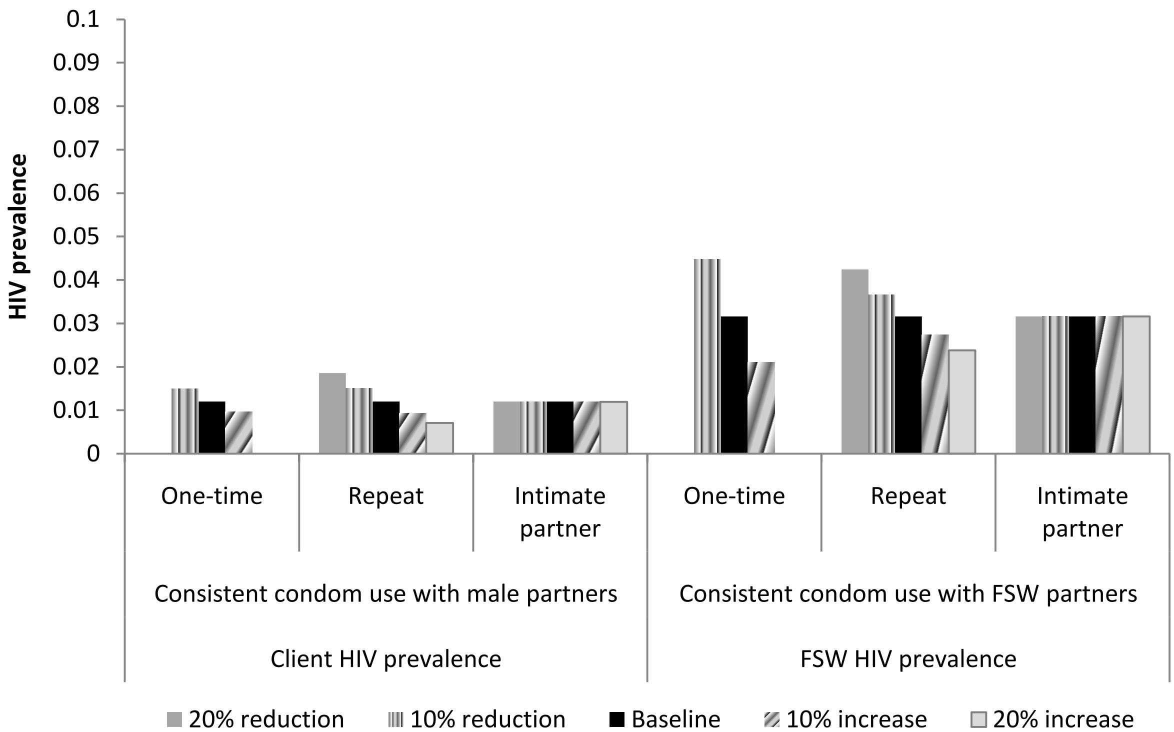
As expected, varying the FSW population size had a modest impact and mainly early in the epidemic. Increasing the size of FSW population essentially slowed the increase in prevalence but affected its peak marginally. Varying the fraction of FSWs with intimate partners, the numbers of intimate partners per FSW, and the numbers of sex acts per intimate partnership had a small impact on the HIV epidemic. This is due to the low number of intimate partners that FSWs reported having compared to the number of commercial sex clients. Figure 4.5 displays the relatively minor impact of varying CCU with each type of sex partner in 2005 from the baseline estimated values. The impact on HIV prevalence in 2015 of varying CCU with clients in 2005 was small because of the relatively high CCU in 2005. The impact also was small when varying CCU with intimate partners because of the estimated low contribution of intimate partnerships to the epidemic. Due to the high levels of condom use after the introduction of the Avahan AIDS Initiative, sexual structure had a relatively reduced impact on the epidemic post-intervention (results not shown).

Figure 4.4: Impact of varying each sexual structure parameter through a wide range (half to double the baseline value) on peak HIV prevalence in Belgaum (baseline district).[1,]



[1]Red bars=a positive correlation and grey bars=a negative correlation. Bars are arranged in the order of the absolute impact of each parameter on peak HIV prevalence. FSW=female sex worker; CLI = male client of female sex worker.

Figure 4.5: HIV prevalence among female sex workers and their clients in 2015 in Belgaum (baseline district), according to condom use by different types of partners (e.g., occasional and repeat clients, and intimate partners). Condom use was varied from a 20% reduction to a 20% increase in condom use in 2005.[1]



[1]10% only for occasional clients, since increasing above 10% would result in >100% condom use as condom use was already high in 2005.

- Second: explaining differences in HIV prevalence between the three districts

Table 4.3 displays the percent change in HIV prevalence in Bellary and Bangalore when individual sexual structure parameter values from Belgaum were substituted for the values in each of these districts. Results indicated that using Bellary's heterogeneous distribution of the numbers of clients per FSW, holding the values for all other parameters at Belgaum's values, produced HIV prevalence amongst FSW that was lower than in Belgaum in 2005 but still higher than observed in Bellary (model: 21.3%; observed: 15.6% [11.1-20.0]). However, it was within-range of that observed for clients (model: 4.8%; observed: 6.0% [2.6-9.5]). This suggests that the difference in the numbers of clients of FSWs could explain part of the difference in FSW HIV prevalence between Bellary and Belgaum and all the difference among clients. Bellary's lower observed FSW HIV prevalence could be explained solely by reducing Belgaum's numbers of sex acts reported with repeat clients to Bellary's values, as this decreased 2005 HIV prevalence among FSWs and clients by 61% and 71% respectively. In this case, client HIV prevalence was lower than observed in Bellary. Conversely, reducing the average duration of repeat partnerships from the Belgaum to the Bellary values increased HIV prevalence in 2005 among FSWs and clients by 21% and 35% respectively.

Using Bangalore's heterogeneous distribution of the numbers of clients per FSW (holding the values for all other parameters at Belgaum's values) produced HIV prevalence that was lower than observed in Bangalore in 2005 among FSWs (model: 3.7%; observed: 12.7% [8.6-16.7] and clients (model: 0.8%; observed: 2.4% [0.9-3.9]). Results from the univariate sensitivity analysis indicated that alternatively, Bangalore's lower observed HIV prevalence (compared to Belgaum) could also be explained by Bangalore's larger FSW population size, and partially explained by Bangalore's shorter duration of sex work and lower numbers of sex acts with repeat clients (Table 4.3). Substituting the values for these parameters decreased model HIV prevalence in 2005 in FSWs by 195%, 54% and 27%, respectively, and in clients by 10%, 12% and 44%, respectively. Conversely, 2005 HIV prevalence in FSWs and clients was increased by 32% and 49%, respectively, when Bangalore's shorter duration of repeat client partnerships was accounted for. The impact of remaining sexual structure parameters on explaining HIV prevalence between Belgaum, Bellary and Bangalore is provided in Table 4.3. Some additional parameters were also influential, but in the opposite direction that what was expected (e.g., Bangalore's values for duration of the repeat client partnership, number of visits by clients to FSWs and fraction of repeat FSWs). The absolute relative changes in 2005 HIV prevalence among FSWs and clients were very small (<5%) for other parameters (e.g., Bellary's duration of sex work; both districts' values for duration of being a client, fraction of FSWs with an intimate partner, number of sex acts with intimate partners and numbers of intimate partners over a lifetime).

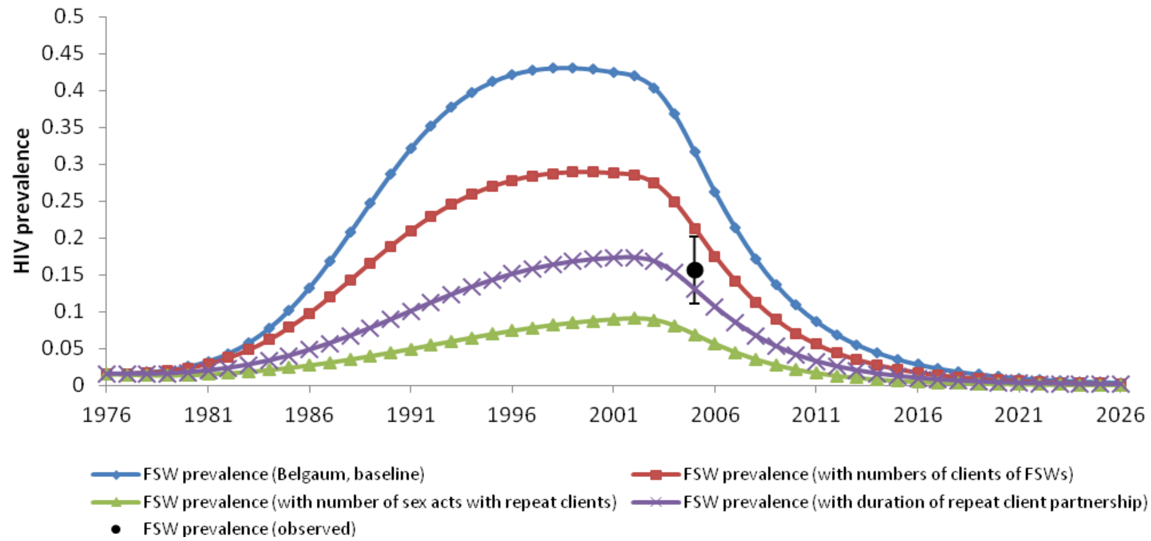
A step-by-step process to simply fit a model to observed HIV prevalence in each of Bellary and Bangalore was undertaken. Starting with Belgaum's baseline parameter values, district-specific values for the sexual structure parameters from Bellary and Bangalore were substituted together. The Bellary/Bangalore value for each parameter was added to the previous value (Figure 4.6a and 4.6b). To produce a model that fit to observed FSW HIV prevalence in Bellary in 2005 (and client prevalence in 2008), the values of three sexual structure parameters from Bellary were substituted together (model: FSWs: 13.0%; clients: 2.6%). Since all other parameters were held constant at Belgaum's values, this suggests that these three parameters combined could explain all the difference in HIV prevalence between Bellary and Belgaum. To produce a model that fit to observed FSW HIV prevalence in Bangalore in 2005 (and client prevalence in 2008), the values of six parameters from Bangalore were substituted together (model: FSWs: 12.5%; clients: 4.9%). Table 4.2b highlights the parameters used to produce a model fit to observed HIV prevalence in Bellary and Bangalore.

Table 4.3: The relative change in HIV prevalence in Bellary and Bangalore when substituting individual sexual structure parameter values from Belgaum to the values in each of these districts.

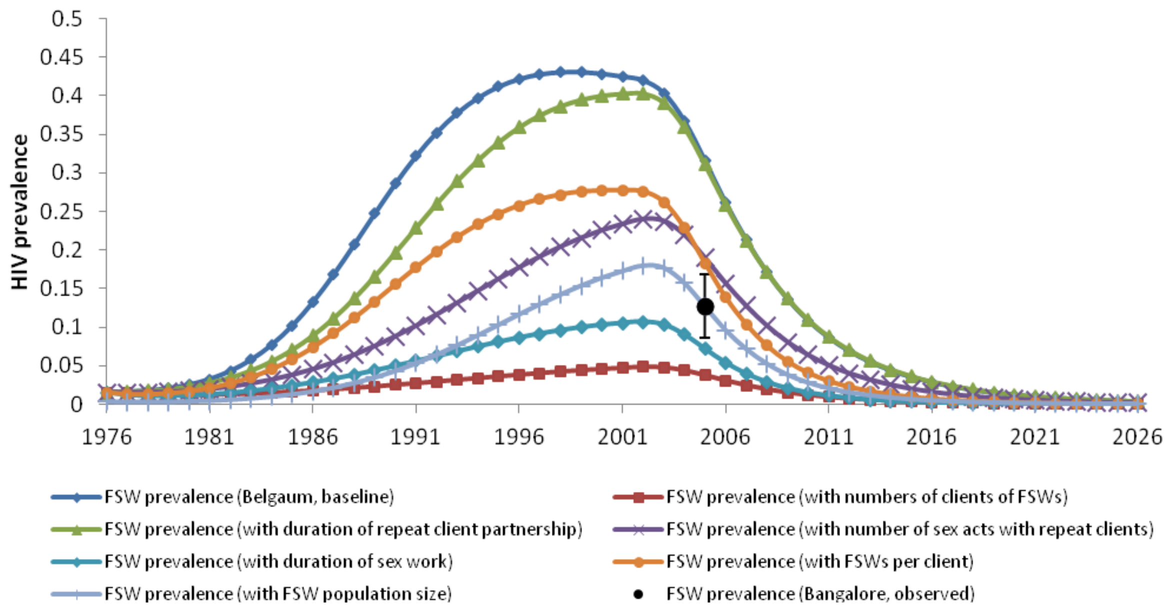
	Belgaum			Bellary					Bangalore				
		HIV prevalence			HIV prevalence		Percent change			HIV prevalence		Percent change	
	Value	FSW	Client	Value	FSW	Client	FSW	Client	Value	FSW	Client	FSW	Client
FSW population size	2000	31.6%	6.5%	3250	30.7%	6.3%	-2.9%	-3.1%	12600	10.7%	5.9%	-195.3%	-10.2%
Numbers of clients per FSW per month	56	31.6%	6.5%	46	21.3%	4.8%	-32.6%	-26.2%	34	3.7%	0.8%	-754.1%	-712.5%
Number of visits to FSWs by clients per six months	3.6	31.6%	6.5%	4.2	35.7%	8.1%	12.9%	24.6%	4.7	38.3%	9.4%	17.5%	30.9%
Fraction of repeat clients (of FSWs)	35 %	31.6%	6.5%	44%	28.9%	6.0%	-8.5%	-7.7%	29%	33.1%	6.7%	4.5%	3.0%
Fraction of repeat FSWs (of clients)	0.17	31.6%	6.5%	0.19	34.2%	7.5%	8.2%	15.4%	0.22	37.4%	8.9%	15.5%	27.0%
Duration of repeat client partnership (months)	31.2	31.6%	6.5%	24	38.1%	8.8%	20.6%	35.4%	18	46.2%	12.7%	31.6%	48.8%
Numbers of sex acts with repeat clients (per year)	4.1	31.6%	6.5%	2.6	12.2%	1.9%	-61.4%	-70.8%	3.6	24.8%	4.5%	-27.4%	-44.4%
Duration of sex work (years)	9.7	31.6%	6.5%	8.7	30.7%	6.5%	-2.9%	0.0%	3.9	20.5%	5.8%	-54.2%	-12.1%
Duration of being a client (years)	8.5	31.6%	6.5%	8.5	31.6%	6.5%	0.0%	0.0%	9.1	32.3%	6.9%	2.2%	5.8%
Fraction of FSWs with a main intimate partner	52.4%	31.6%	6.5%	64.3%	31.6%	6.5%	0.0%	0.0%	69.0%	31.6%	6.5%	0.0%	0.0%
Number of sex acts with intimate partners (per year)	7.5	31.6%	6.5%	8.3	31.6%	6.5%	0.0%	0.0%	8.8	31.6%	6.5%	0.0%	0.0%
Number of intimate partners (over lifetime)	1.4	31.6%	6.5%	1.3	31.4%	6.5%	-0.6%	0.0%	1.8	30.8%	6.3%	-2.6%	-3.2%

Figure 4.6: Results from the univariate sensitivity analysis undertaken to fit a model to observed HIV prevalence in each district. The model fitting process for each district started with a model fit to Belgaum (baseline district) and iteratively added other sexual structure parameters from other districts, including:[1]

(a) A univariate sensitivity analysis using Bellary's parameters.



(b) A univariate sensitivity analysis using Bangalore's parameters.



[1]A step-by-step process to simply fit a model to observed HIV prevalence in each of Bellary and Bangalore was undertaken. Starting with Belgaum's baseline parameter values, district-specific values for the sexual structure parameters from Bellary and Bangalore were substituted together. The Bellary/Bangalore value for each parameter was added to the previous value. In other words, to fit the model to Bellary's HIV prevalence, the numbers of clients of FSWs was substituted first, followed by the numbers of sex acts with repeat clients and the duration of the repeat client partnerships. To fit the model to Bangalore's HIV prevalence, the numbers of clients of FSWs was substituted first, followed by duration of the repeat client partnership, numbers of sex acts with repeat clients, duration of sex work, numbers of visits to FSWs by clients and FSW population size.

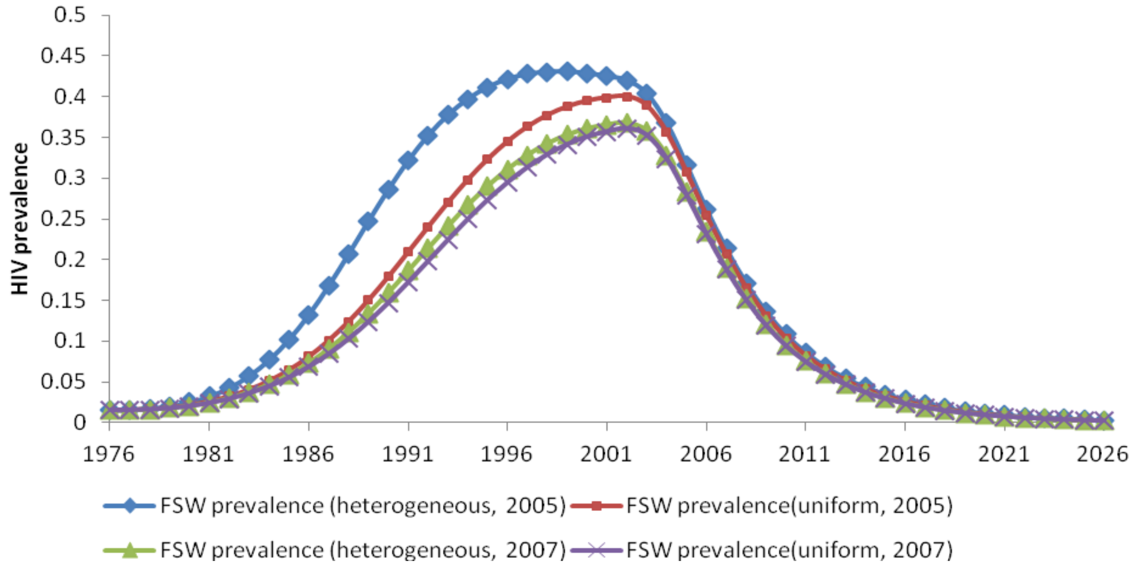
- Third: influence of distributions of the numbers of clients within districts on HIV prevalence

Figures 4.7a to 4.7f show the FSW and client HIV prevalence for four different distributions of the numbers of clients of FSWs in each district: using either a heterogeneous or uniform distribution from either 2005 or 2007. Model results indicate that substituting the uniform for the heterogeneous distribution had the largest impact on HIV prevalence among FSWs and clients in Belgaum (for the 2005 distribution) and Bellary (for both the 2005 and 2007 distributions). In these cases, HIV prevalence among FSWs and clients increased much more rapidly with the heterogeneous compared to the uniform distribution. Peak prevalence was higher for FSWs and clients with the heterogeneous compared to the uniform distributions in Belgaum (2005) and Bellary (2005), and for clients in Bellary (2007). The original continuous distributions of the numbers of clients of FSWs in these districts also had the largest Gini coefficients and variance (Table 4.2a). The increased variability in the numbers of clients of FSWs in these districts is reflected in the relatively large sub-populations with much higher than average numbers of clients (Figure A2.1a, A2.1c and A2.1d). In these cases, tailoring interventions toward these sub-populations rather than to the entire population of FSWs could theoretically have a larger impact on reducing HIV prevalence. For Bangalore (2005), HIV prevalence curves for FSW and clients had similar shapes (i.e., peaked at the same time) for the heterogeneous compared to the uniform distribution, but peak prevalence was higher. For Belgaum (2007) and Bangalore (2007), the differences between HIV prevalence in FSWs and clients for the heterogeneous compared to the uniform distributions were marginal. In these cases, the original continuous distributions had lower Gini coefficients and variance (Table 4.2a). Sub-population means were similar to the population mean (Figure A2.1b, A2.1e and A2.1f). Thus, there was little impact from substituting the heterogeneous and the uniform distributions.

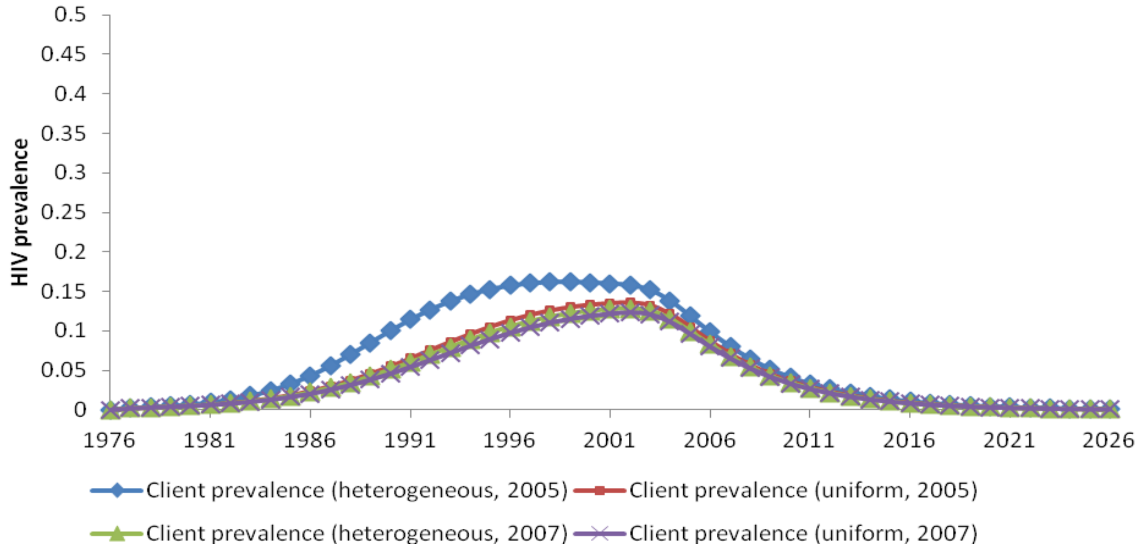
In these cases, tailoring interventions toward these sub-populations would likely have a similar impact on HIV prevalence as tailoring interventions to the entire population of FSWs.

Figure 4.7: The impact of varying heterogeneous and uniform distributions on HIV prevalence among female sex workers and clients in Karnataka, India, including:

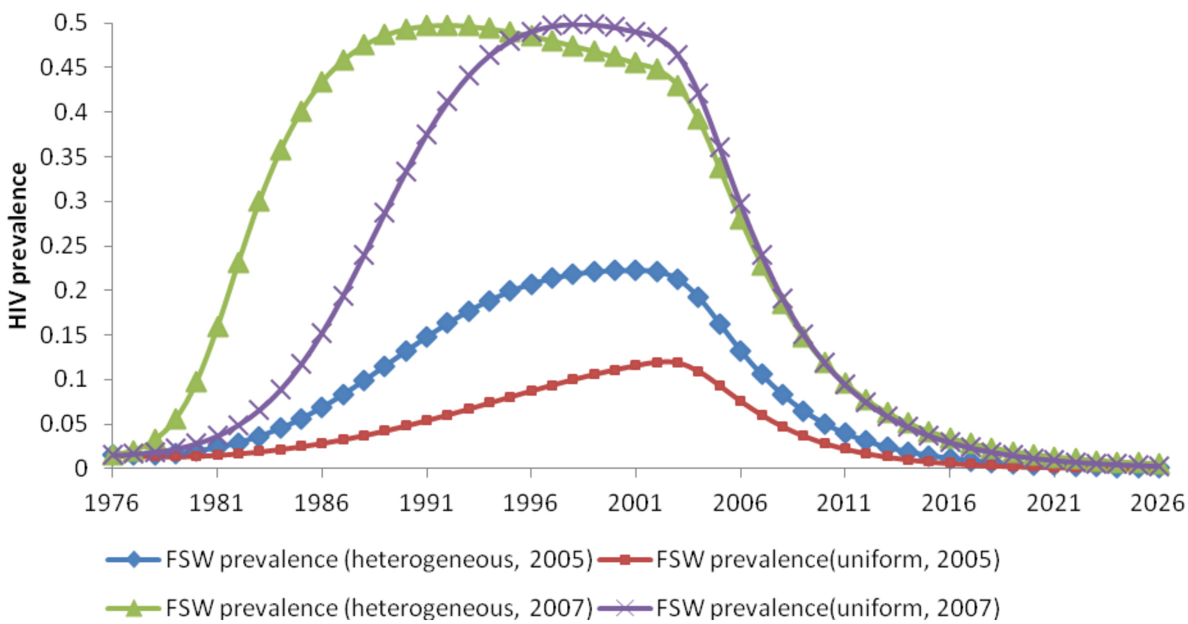
(a) Female sex workers in Belgaum.



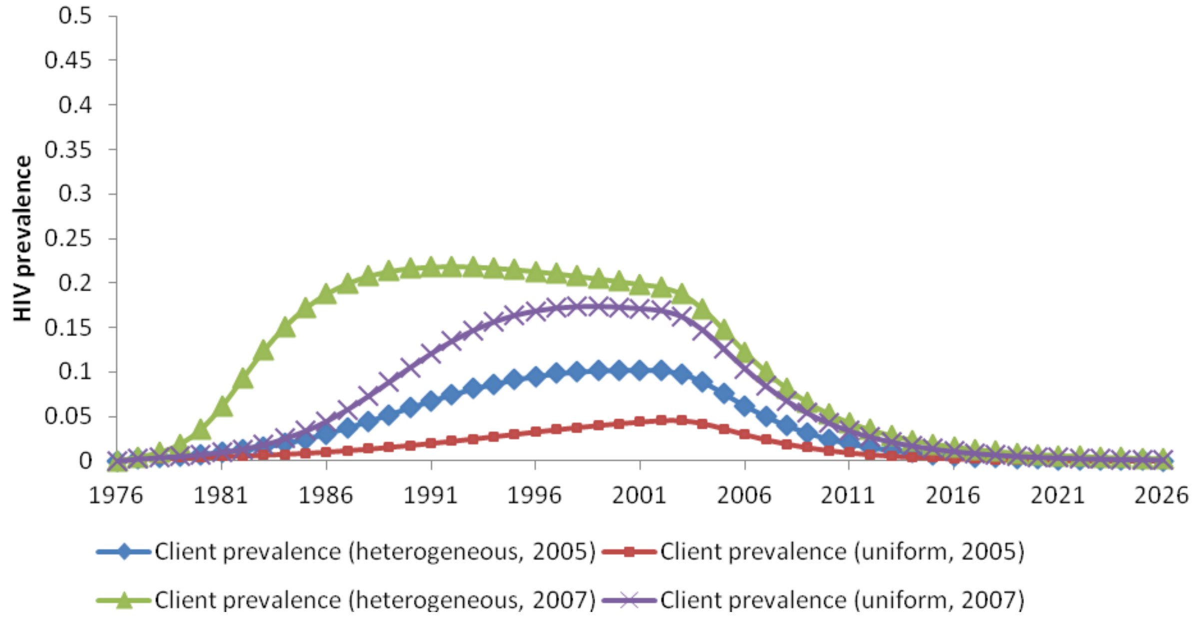
(b) Clients of female sex workers in Belgaum.



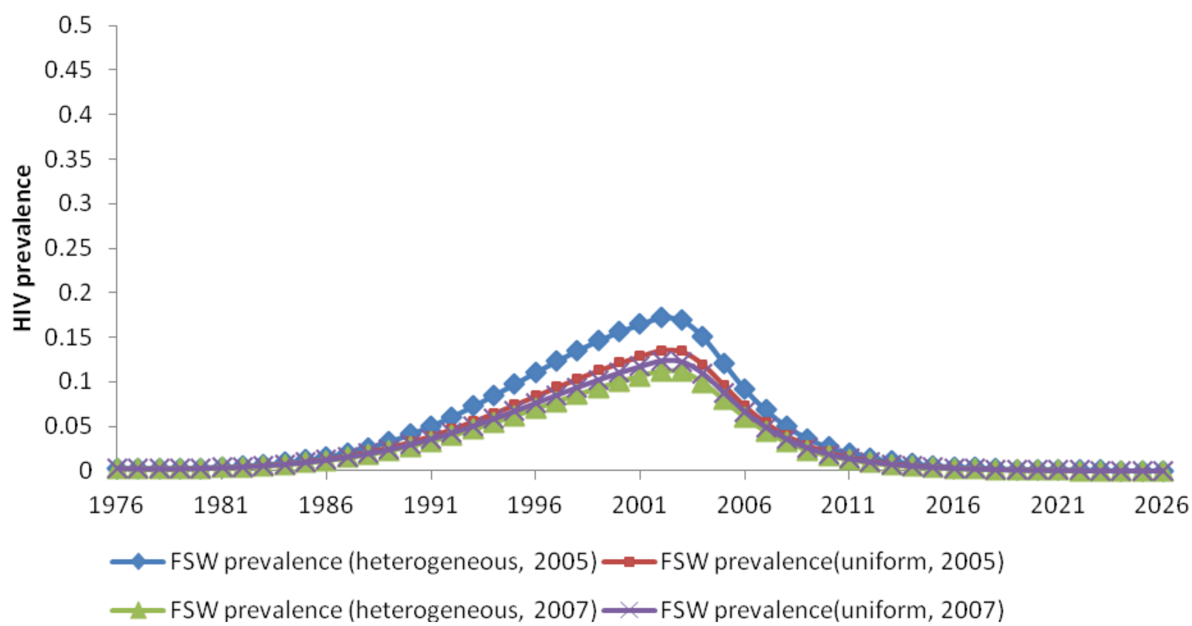
(c) Female sex workers in Bellary.



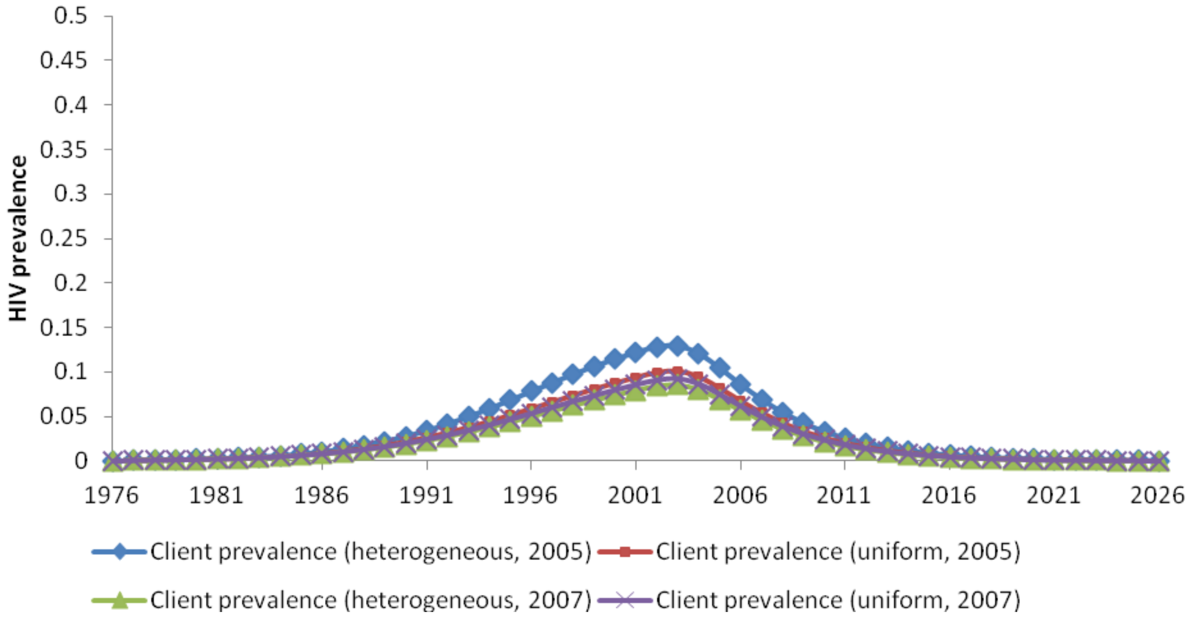
(d) Clients of female sex workers in Bellary.



(e) Female sex workers in Bangalore.



(f) Clients of female sex workers in Bangalore.



4.5 DISCUSSION

This analysis described substantial heterogeneity in sexual structure within and across three districts in Karnataka state, southern India. The epidemiological parameters that had the largest influence on increasing simulated HIV prevalence included the numbers of clients of FSWs, the numbers of visits to FSWs by clients, and the numbers of sex acts within repeat client partnerships. The parameters with the largest influence on decreasing simulated HIV prevalence were a longer duration of the repeat FSW partnership reported by clients (which decreased the numbers of repeat FSWs visited by clients per year) and a higher fraction of repeat clients of FSWs (which decreased the numbers of occasional clients of FSWs per year). However, different results could have been generated under different simulated assumptions. Differences in sexual structure could help explain observed differences in HIV prevalence on a population level across districts. Increased heterogeneity in the numbers of clients of FSWs resulted in a faster spread of

HIV infection and/or higher peak HIV prevalence within districts, or had little impact, depending on the setting.

Aggregate measures of the numbers of clients of FSWs (e.g., averages) can be useful to characterize HIV risk among FSWs on a population level. In this analysis, increasing the average numbers of clients of FSWs and visits to FSWs by clients had the largest impact on HIV prevalence in the baseline district relative to other sexual structure parameters, highlighting the sensitivity of HIV prevalence to partner rates (this was validated in other districts – results not shown). However, results also indicated that other epidemiological parameters that define the sexual structure (e.g., those related to repeat client partnerships) can strongly influence the trajectory of HIV infection among FSWs and their male partners, which may also be correlated with HIV risk in the general population [Alary et al., 2010]. Results also suggested that the heterogeneity in some features of sexual structure observed across these districts could be sufficient to explain the observed heterogeneity in HIV prevalence. These results together are consistent with conceptual studies of HIV and simulation studies of STI prevalence [Blanchard et al., 2007, Blanchard et al., 2008b, Blanchard and Aral 2010, Ghani and Aral 2005]. The current analysis also showed that heterogeneous distributions of the numbers of clients of FSWs (i.e., sub-populations have sub-population averages), relative to uniform distributions (i.e., sub-populations have population average), within districts, can sometimes increase the spread of the epidemic as well as peak prevalence. This was the case in districts when the distribution of the numbers of clients of FSWs was more variable, as in Bellary (2005 and 2007) and Belgaum (2005). (e.g., higher Gini coefficients and higher variance). When the numbers of clients of FSWs were more evenly distributed across the population, the population average was a relatively good proxy for the heterogeneous distribution for predicting HIV prevalence.

It is important to examine the epidemiological parameters that define sexual structure in synchrony for several reasons. First, differences in observed HIV prevalence between districts could not always be explained by observed differences in the value of a single parameter. In some cases, the differences in the observed value of a parameter caused HIV prevalence to shift in a direction that was counterintuitive (based on the relative differences in HIV prevalence actually observed between districts). For example, the shorter duration of the repeat client partnership and higher fraction of repeat FSWs observed in both Bellary and Bangalore predicted HIV prevalence in 2005 that was much higher than observed in these districts. To explain the observed differences in HIV prevalence across districts, the model required a unique set of sexual structure parameters from each district. Second, the impact of each sexual structure parameter on HIV prevalence depended on the values of other parameters, since many of these parameters were correlated to satisfy the balancing activity constraint (i.e., keeping the total number of FSW-client/client-FSW partnerships equal). The rules defining *how* these parameters are correlated were based on assumptions that are difficult to verify in reality, but nevertheless influenced the outcomes of this analysis.

For example, according to this analysis (and the model assumption that an increased fraction of repeat clients leads to a decrease in the numbers of occasional clients), HIV prevalence could decrease or remain lower, even if the overall client-FSW contact rate remained high. This could happen in settings where FSWs tend to have or are moving toward having more repeat clients (e.g., increased collectivization of FSWs and 'sharing' of repeat clients within smaller groups [O'Brien 2009]). FSW size also has been identified as an important parameter in influencing STI and HIV prevalence and the impact of interventions [Ghani and Aral 2005, Williams et al., 2006] and, in the current analysis, an increase in the size of the FSW population resulted in marginally reduced HIV prevalence in 2005. This was due to the model structure, whereby the client population size was determined by the size of the FSW population, while sexual behaviour was held constant. Larger population sizes result in slower spread of HIV, although peak and equilibrium prevalence remained the same. Other assumptions could be made; for example, if a larger FSW size resulted in higher numbers of FSWs per client (Equation 4.2), this would likely increase prevalence [Ghani and Aral 2005]. A more thorough empirical understanding of the complex interactions between the sexual behaviour of individuals in a population is required to develop model assumptions that better reflect reality and predict the impact of changes in sexual structure parameters.

This analysis found that varying sexual structure parameters related to intimate sex partnerships had a smaller impact on HIV prevalence than commercial partnerships. Although this is consistent with studies that identify commercial partnerships as being the most important to the spread of HIV [Arora et al., 2004, Vickerman et al., 2010], these results should be interpreted with caution. Due to the limited data available on the intimate partners of FSWs, several assumptions were made that could have produced this relatively low impact on HIV prevalence. For example, an increase in the numbers of intimate partners per FSW increased the size of the intimate partner population. Since the total number of males in the population was assumed to remain constant in the simulations, this decreased the total number of clients in the population (since a low fraction of intimate partners were assumed to be clients) and reduced HIV prevalence. The potential for HIV transmission to FSWs from their intimate partners could be higher than predicted by the model if the population of intimate partners was much larger, if male intimate partners of FSWs frequently had other casual FSW sex partners (concurrency), or if they engaged in other sexual behaviour that could place them at higher risk for HIV infection (e.g., lower condom use with casual FSW partners). This is because condom use is lower in intimate partnerships, including with FSWs [Barrientos et al., 2007, Chan and Man 2002, Figueroa et al., 2007, Gorbach et al., 2006, Luke 2006, Murray et al., 2007, Voeten et al., 2007, Wang et al., 2007a].

Migration or mobility of FSWs was not included in the model. Movement of FSWs and clients could, however, play an important independent role in changing the local distribution of the numbers of clients or patterns of sexual contact, as well as HIV transmission dynamics [Blanchard et al., 2007, Coffee et al., 2007, Deering et al., 2008]. For example, it is unclear if migrants to an area tend to have repeat or occasional sex partners locally or how the local sex work structure adapts to meet changing needs due to an influx of new clients. A model that could explore more detailed assumptions of sex partner contact structure, such as concurrency of repeat or intimate partnerships and gaps between partnerships, could also provide insights into HIV transmission [Aral 2008, Morris and Kretzschmar 1997, Watts and May 1992]. Concurrency has likely played a small role in influencing FSW HIV prevalence in southern India, since HIV transmission to FSWs occurs primarily through high volumes of clients. It is unclear, however, how and if this would change in post-intervention settings where condom use in occasional commercial partnerships is approaching 100%, while remaining low with more intimate partnerships.

Results from this study identified key sexual structure parameters relating to commercial sex work that were important to HIV transmission dynamics in a southern Indian setting, as well as those parameters that could explain differences in HIV prevalence across geographic regions. Due to the relatively large influence of sex partnering patterns of FSWs and their clients on HIV prevalence, in addition to aggregate average numbers of sex partners, sex partnering patterns within local contexts should be considered in the design and monitoring of interventions. The heterogeneous risk faced by FSWs needs to be recognized in order to explain differences in HIV epidemics among FSWs and to inform effective and population-specific interventions that are capable of addressing the complexities implied by heterogeneity. Vulnerable sub-populations of FSWs should be identified and interventions should be tailored toward these women to have a substantial influence on the HIV epidemic. Moreover, in light of findings related to differences in sexual structure across districts, HIV prevention planners need to tailor interventions to respond to local contexts.

CHAPTER 5

THE RELATIONSHIP BETWEEN EXPOSURE TO A LARGE-SCALE CORE GROUP HIV PREVENTION INTERVENTION AND CONDOM USE WITH DIFFERENT TYPES OF SEX PARTNERS OF FEMALE SEX WORKERS IN SOUTHERN INDIA

5.1 INTRODUCTION

Sex work-related harms are linked inextricably to the social, economic, policy, and physical environments of sex workers. Individual behaviour (high- or low-risk) both shapes and is shaped by individual and environmental factors [Rhodes 2002, Rhodes and Simic 2005]. Thus, there is an increasing recognition of the importance of using structural and community-level strategies that modify sex work environments to reduce risk and promote health among sex workers and their clients [Buzdugan et al., 2009, Harcourt and Donovan 2005, Shannon et al., 2008a, Shannon et al., 2008b]. Notably, in response to high rates of HIV and sexually transmitted infections (STIs) among female sex workers (FSWs) in the early 1990s, several countries in east Asia instituted campaigns to promote 100% condom use so as to increase social acceptance of condoms, influence men to agree to use condoms and encourage FSWs to demand condom use with clients. These programmes also aimed to increase access to STI testing and treatment and are thought to have contributed to dramatic declines in STIs and HIV in Thailand and Cambodia, as well in other settings across Asia [Hanenberg et al., 1994, Jana et al., 2006, Rojanapithayakorn 2006]. The Sonagachi Project in Kolkata, India, implemented a community empowerment model for sex workers that framed health risks as occupational hazards, focusing on addressing combinations of community- and individual-level factors influencing risk for HIV.

Subsequently, large increases in condom use have been observed and HIV prevalence remains low in FSWs associated with Sonagachi Project [Cohen 2004, Jana et al., 2004, Jana et al., 2006].

Another large-scale intervention designed to reduce HIV infection rates among core groups (e.g., FSWs; men-who-have-sex-with-men; injection drug users) and bridge groups (e.g., clients of FSWs) is Avahan, the India AIDS Initiative [Avahan, the India AIDS Initiative - the Business of HIV prevention at Scale 2008, Piot 2010], which began in 2003 in the six states with the highest HIV prevalence in India. Using community empowerment strategies, combined with condom promotion and STI clinical services among these populations, the ongoing Avahan AIDS Initiative addresses proximal and distal determinants of risk. The Avahan AIDS Initiative aims to increase condom use among core and bridge groups by modifying their environments to enable individuals to use condoms [Sarkar 2010]. For FSWs, this is achieved through a combination of approaches. The Avahan AIDS Initiative includes peer-led outreach to increase awareness of condoms and ability to negotiate condom use with clients [Managing HIV prevention from the ground up: Avahan's experience in peer led outreach at scale in India 2008], efforts to increase the availability of and access to condoms and STI testing and treatment centres, and actions to improve community mobilization [Avahan, the India AIDS Initiative - the Business of HIV prevention at Scale 2008, Blankenship et al., 2010]. The evaluation of this large-scale intervention remains challenging, as is the case for many similar evaluation efforts where conventional methods (e.g., randomized control trials of communities) are unethical and/or impractical to implement [Boily et al., 2007b, Piot 2010]. A multi-pronged evaluation framework is necessary to gain an overall understanding of an intervention's impact [Boily et al., 2007b]. This includes an examination of programmatic (e.g., numbers of peer educators, clinics or services to meet the population's needs) and health indicators (e.g., increases in condom use, decreases in HIV or STI incidence). The consistency of study results from a combination of study designs, including transmission dynamics modelling (e.g., testing hypotheses while taking into account uncertainty in parameter estimates), cost-effectiveness analysis, surveillance and epidemiological approaches, can together provide a stronger understanding of the effectiveness of the intervention [Szklo and Nieto 1999].

As part of this comprehensive evaluation framework, the objective of the current analysis was to determine if the Avahan AIDS Initiative had an impact on condom use amongst FSWs in urban areas of three districts in Karnataka State, India. The HIV prevalence in these districts among FSWs was 12.7% in Bangalore district, 15.7% in Bellary and 33.9% in Belgaum in the mid-2000s [Ramesh et al., 2008]. Specifically, this analysis assessed the association between five different intervention exposure variables and the following five measures of consistent condom use (CCU) (i.e., 100%) as reported by FSWs by: (1) all clients on the most recent day worked; (2) their current occasional clients; (3) their most recent repeat client; (4) their most recent non-paying partner and (5) their husbands/cohabiting partner. To strengthen the evidence of a causal relationship, a dose-response association was examined between three variables measuring exposure to the intervention and condom use.

5.2 METHODS

Study design and sampling

During 2005-06, in-depth, face-to-face interviews (Special Behavioural Surveys, SBS) were conducted with 775 FSWs in three districts in Karnataka state, located in southern India. A probability sampling method was employed, using time-location cluster sampling with normalized weights calculated to account for the sampling design. Sampling methods were similar to those reported by Ramesh et al 2008 [Ramesh et al., 2008] for other studies carried out among FSWs in Karnataka state.

Survey organization and methods

The surveys were implemented by the CHARME-India project in collaboration with the Institute of Population Health and Clinical Research (IPHCR), St John's Medical College, and the Karnataka Health Promotion Trust (KHPT) Bangalore, India, the Centre hospitalier *affilié* universitaire de Québec (CH*A*), Québec, Canada, and the University of Manitoba, Winnipeg, Canada. The surveys were administered by trained interviewers in the local language (*Kannada*) and were conducted anonymously, with no names or personal identifiers recorded. Ethics approval was attained from the CH*A* and the University of Manitoba as well as St. John's Medical College.

Outcomes

The first outcome, CCU by all clients as reported by FSWs (including both occasional and repeat clients) during all instances of sexual intercourse in the most recent day worked (i.e., did sex work) was derived by dividing the reported number of instances of sexual intercourse in which condoms were used by the reported total reported number of instances of sexual intercourse in the most recent day worked. This was used to create a dichotomized variable of 100% versus <100% of instances of sexual intercourse in which condoms were used. The remaining outcomes described CCU by FSWs' different sex partners, as reported by FSWs, including: their current occasional clients; their most recent repeat client; their most recent non-paying partner (excluding husbands/cohabiting partners); and their husband/cohabiting partner. These outcomes were derived from survey items about general condom frequency by each type of partner (e.g., “How often do you use condoms with <this partner>?”). Condom use was considered to be CCU by their partners, if they answered ‘always’, as opposed to ‘often’, ‘sometimes’ or ‘never’.

Explanatory factors

This analysis examined the independent impact of five variables measuring exposure to the intervention, including: (i) if FSWs had been contacted by intervention staff; (ii) if FSWs had been given condoms by intervention staff; (iii) the duration of time since first contacted by intervention staff (years); (iv) the number of times in the past month FSWs had been contacted by intervention staff; and (v) the number of condom demonstrations by intervention staff that FSWs had seen in the past month.

The effects of social and environmental factors were adjusted for in multivariable analysis. Social factors included age, marital status (including the *Devadasi* tradition, a form of temple-based sex work whereby women are dedicated through marriage to gods or goddesses) [Blanchard et al., 2005, O'Neil et al., 2004, Orchard 2007], religion, age at first sex, age at first sex work, duration of sex work, if respondents currently had repeat clients, their current number of repeat clients, their number of days worked in a typical month, their number of total clients per most recent day and if they currently had a non-commercial sex partner. Environmental factors included district of residence, education (literacy) and having sex work as sole income (no other paid work versus any, including non-agricultural labour, petty business, maid servant, agricultural labour, handicrafts and other). It also included FSWs’ working environment, which was represented by the type of solicitation (independent or through a middleman/pimp) and the places of solicitation of clients of FSWs, which were grouped into three categories: home-based (home; rented room), brothel-based (lodge; *dabha* [road-side lodge-type establishment]; bar/night club; brothel); and public places-based (vehicle; public places, such as bus stops, train stations and the street).

Statistical analysis

Statistical analysis was conducted using survey methods in SAS Version 9.1 [SAS 2002-03], taking into account the sampling clusters and weights. Descriptive statistics were calculated for sample characteristics. The prevalence of the five CCU outcomes was calculated by each variable describing exposure to the intervention. Bivariate and multivariable logistic regression was used to model the relationship between the different CCU outcomes and the five variables describing exposure to the intervention. Separate logistic models were created for each of the five dichotomous CCU outcomes and each of the five intervention exposure variables, for a total of 25 separate models. Inclusion of social and environmental factors variables into multivariable models was based on significance at the p<.10-level from Wald chi-squared tests in bivariate regression analyses, or if these factors were perceived to be important confounders *a priori* (district, typology of sex work). Each single intervention variable was forced into the five different multivariable models to examine the independent relationship between intervention exposure and CCU. Two intervention exposure variables were dichotomous (ever been contacted by intervention staff, ever seen a condom demonstration by intervention staff), while three were originally continuous (duration since first contacted by intervention staff, number of times contacted by intervention staff, number of condom demonstrations given by staff). The continuous variables were categorized prior to analysis, based on perceived relevance to the program. To examine a dose-response relationship, a linear test for trends across categories for each of the three continuous intervention exposure variables and each CCU outcome was conducted. The median of each category was taken, and the exposure variable was treated as a continuous variable. Odds ratios (ORs) and adjusted odds ratios (AORs) and their 95% confidence interval [95% CIs] were reported for logistic regression and *p*-values were reported for the tests for trends. All *p*-values reported are two-sided.

5.3 RESULTS

Sample characteristics

Table 5.1 presents characteristics of the overall sample of FSWs in three districts in Karnataka state. The sample sizes for Belgaum, Bellary and Bangalore were 208, 198 and 369 (N=775) respectively, and the median age of FSWs across the three districts was 30 years (interquartile range [IQR]=25-35; mean=30.3 years). Of the total sample, the majority of women, 348 (55.6%), primarily solicited clients in public places, while 245 (26.2%) solicited clients from their homes and 182 (18.2%) in brothels. Overall, 371 (52.5%) women in the sample were divorced, separated or widowed, 229 (26.0%) were currently married, 119 (15.5%) were *Devadasi* and 56 (5.9%) were other women who were never married (Table 5.1).

Table 5.1: Sample characteristics and bivariate associations (unadjusted odds ratios [OR] and 95% confidence intervals [95% CIs]) between social, environmental and intervention exposure factors and consistent condom use by commercial clients of female sex workers in Karnataka state, India.

	Proportion (n) or mean /median (interquartile range)	OUTCOMES					
		Condoms used in each occasion of sexual intercourse with all clients in the most recent day worked		Consistent condom use with occasional clients		Consistent condom use with most recent repeat client	
	N=775	OR [95% CIs]	*p*	OR [95% CIs]	*p*	OR [95% CIs]	*p*
SOCIAL							
Age (years)	30.3/ 30 (25-35)	1.00 [0.97-1.03]	0.935	0.97 [0.93-1.00]	0.081	0.97 [0.93-1.02]	0.188
Marital status							
Devadasi	15.5 (119)	1.73 [0.73-4.08]	0.268	2.27 [1.18-4.34]	0.031	1.30 [0.64-2.66]	0.729
Never married	5.9 (56)	0.65 [0.26-1.63]		1.02 [0.47-2.22]		1.26 [0.50-3.18]	
Divorced/Separated/ Widowed	52.5 (371)	0.93 [0.49-1.76]		0.94 [0.54-1.64]		0.77 [0.28-2.09]	
Currently married	26.0 (229)	1.0 (ref)		1.0 (ref)		1.0 (ref)	
Religion							
Hindu (versus other - Islam/ Christian/ Jain)	89.1 (682)	1.01 [0.51-1.98]	0.981	1.27 [0.69-2.33]	0.445	0.53 [0.20-1.41]	0.206
Age at first sex (years)	15.5/ 15 (14-17)	1.12 [1.01-1.24]	0.036	1.07 [0.94-1.22]	0.295	1.06 [0.98-1.16]	0.137
Age at first sex work (years)	23.8/ 23 (18-29)	0.99 [0.96-1.03]	0.734	0.96 [0.93-0.99]	0.006	0.97 [0.92-1.03]	0.269
Duration of sex work (years)	6.5/ 5 (2-10)	1.01 [0.96-1.05]	0.744	1.00 [0.95-1.06]	0.892	0.99 [0.95-1.04]	0.786
Has at least one repeat client	59.36 (433)	1.02 [0.65-1.61]	0.930	1.04 [0.70-1.54]	0.832	n/a	
Number of different repeat clients (current)	2.1/ 1 (0-3)	1.05 [0.97-1.14]	0.218	0.94 [0.84-1.06]	0.340	0.96 [0.86-1.07]	0.463
Days worked per month (days)	15.6/ 15 (10-20)	0.97 [0.94-1.01]	0.133	1.01 [0.99-1.04]	0.347	1.01 [0.98-1.05]	0.574
Clients in last day (clients)	2.9/ 2 (2-3)	0.81 [0.73-0.89]	<0.001	0.93 [0.83-1.04]	0.204	0.95 [0.82-1.10]	0.461
Had at least one non-comm. partner last year	30.3 (247)	0.49 [0.32-0.75]	0.001	0.68 [0.44-1.05]	0.085	0.90 [0.38-2.15]	0.810
ENVIRONMENTAL							
District							
Belgaum	26.8 (208)	0.54 [0.30-1.00]	0.124	1.34 [0.81-2.23]	0.237	0.89 [0.32-2.43]	0.005
Bellary	25.6 (198)	0.82 [0.41-1.63]		1.58 [0.91-2.73]		2.50 [0.89-7.04]	
Bangalore	47.6 (369)	1.0 (ref)		1.0 (ref)		1.0 (ref)	

	Proportion (n) or mean /median (interquartile range=IQR) N=775	OUTCOMES Condoms used in each occasion of intercourse with all clients in the most recent day worked OR [95% CIs]	*p*	Consistent condom use with occasional clients OR [95% CIs]	*p*	Consistent condom use with most recent repeat client OR [95% CIs]	*p*
Literate	27.2 (227)	1.47 [0.84-2.58]	0.177	1.67 [1.05-2.64]	0.029	2.27 [1.02-5.05]	0.044
Sex work sole income	35.0 (301)	0.73 [0.45-1.17]	0.186	0.86 [0.57-1.30]	0.468	0.75 [0.32-1.78]	0.519
Independent solicitation	77.4 (555)	0.84 [0.47-1.48]	0.543	0.89 [0.54-1.47]	0.640	1.38 [0.52-3.65]	0.523
Typology							
Brothel	18.2 (182)	0.55 [0.28-1.06]	0.161	1.09 [0.58-2.07]	0.142	0.88 [0.42-1.83]	0.689
Public places	55.6 (348)	0.93 [0.52-1.65]		0.68 [0.41-1.11]		0.66 [0.25-1.71]	
Home	26.2 (245)	1.0 (ref)		1.0 (ref)		1.0 (ref)	
INTERVENTION EXPOSURE							
Ever contacted by intervention staff	85.5 (632)	2.88 [1.56-5.32]	<0.001	2.23 [1.31-3.82]	0.003	1.06 [0.42-2.68]	0.901
Had a condom demonstration by intervention staff	82.0 (591)	3.37 [1.93-5.88]	<0.001	2.45 [1.37-4.39]	0.003	1.00 [0.40-2.48]	0.992
Duration since first contacted by intervention staff							
Has not been contacted	15.4 (143)	1.0 (ref)	0.004	1.0 (ref)	0.012	1.0 (ref)	0.464
Less than one year (greater than zero)	36.1 (240)	3.38 [1.65-6.92]		1.69 [0.94-3.04]		0.65 [0.19-2.29]	
One year	28.0 (198)	2.08 [1.04-4.18]		2.37 [1.23 -4.55]		1.41 [0.61-3.28]	
Two to three years	20.6 (154)	3.47 [1.64-7.33]		2.85 [1.45-5.59]		1.51 [0.65-3.50]	
Test for trends			**0.058**		**0.004**		**0.165**
Number of times contacted by intervention staff							
Zero	15.1 (146)	1.0 (ref)	0.006	1.0 (ref)	0.003	1.0 (ref)	0.507
Five or fewer (greater than zero)	63.2 (486)	2.55 [1.36-4.78]		2.54 [1.47-4.42]		1.20 [0.53-2.75]	
Greater than five	21.7 (137)	3.38 [1.32-8.66]		1.80 [0.62-5.27]		0.85 [0.23-3.15]	
Test for trends			**0.075**		**0.821**		**0.603**
Number of condom demos seen past month by staff							
Zero	18.0 (160)	1.0 (ref)	<0.001	1.0 (ref)	<0.001	1.0 (ref)	0.130
One	23.0 (183)	1.99 [1.10-3.61]		1.77 [0.90-3.49]		1.09 [0.49-2.43]	
Two	22.2 (180)	4.72 [2.28-9.77]		4.51 [2.37-8.60]		2.08 [0.94-4.61]	
Three or greater	36.8 (228)	4.48 [1.96-10.28]		2.23 [1.11-4.49]		0.73 [0.21-2.46]	
Test for trends			**0.001**		**0.099**		**0.499**
OUTCOMES[1]							
Condoms used in all occasions of sexual intercourse with clients in the most recent day worked	81.7 (585)						
Consistent condom use[2] with all occasional clients	69.5 (530)						
Consistent condom use[2] with most recent repeat client	57.5 (269)						
Consistent condom use with most recent non-paying partner	31.1 (68)						
Consistent condom use with husband/cohabiting partner	9.6 (40)						

[1]Not all of the outcomes have the same denominator, as the sample was subset to women with different types of partners for each outcome; condoms used in all occasions of sexual intercourse with clients in the most recent day worked has a smaller denominator than consistent condom use with all occasional clients because of missing data in the former outcome.
[2]Consistent condom use is defined as reporting always (100%) using condoms.

Relationship between the intervention and condom use

Condom use with commercial sex clients

The sample of 775 FSWs all reported having occasional clients. Of these women, 433 had repeat clients. Overall, 585 (81.7%) of FSWs reported CCU by all clients in the most recent day worked. In comparison, 530 (69.5%) women reported CCU by current occasional clients and 269 (57.5%) women reported CCU by their most recent repeat client (Table 5.1). CCU by all clients was higher among FSWs who had ever been contacted by intervention staff compared to those who had not (84.6% versus 65.6%), as was CCU by occasional clients (71.9% versus 53.5%) (Figure 5.1a). Similarly, FSWs who had ever been given condoms by intervention staff also reported higher CCU than those who had not (CCU by all clients: 86.6% versus 65.8%; CCU by occasional clients: 73.9% versus 53.6%) (Figure 5.1b). However, CCU by the most recent repeat client was similar for women who had ever been contacted by intervention staff compared to those who had not (57.7% versus 56.2%) and for those who had ever seen a condom demonstration (57.9% versus 58.0%) compared to those who had not.

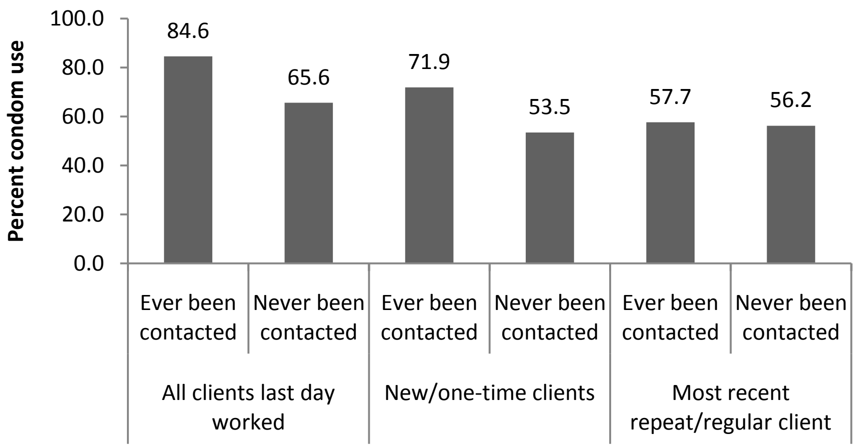
CCU by all clients in the most recent day worked, by occasional clients and by the most recent repeat client increased overall as the duration of time since first contacted by intervention staff increased, but only steadily for CCU by occasional clients (Figure 5.1c). CCU by all clients increased steadily as the number of times contacted by staff in the past month increased (Figure 5.1d). CCU was highest by occasional clients and by the most recent repeat client among women who had been contacted <5 times (relative to women who had never been contacted or who had been contacted 5+ times). Finally, and consistent with the previous outcome, CCU by all clients in the last day worked, by occasional clients and the most recent repeat client increased with the number of condom demonstrations observed in the last month, but levelled off and/or decreased substantially at two condom demonstrations in the last month (Figure 5.1e).

In bivariate analysis, all five intervention variables were significantly associated (on a $p<0.10$ significance level) with CCU by all clients in the most recent day worked and CCU by occasional clients (Table 5.1). Other explanatory variables that were significant on a $p<0.10$-level, or included in multivariable models a priori, are also listed in Table 5.1. In multivariable analysis (Table 5.2), after adjusting for social and environmental factors, the odds of CCU by all clients in the most recent day worked and CCU by occasional clients were 5.3-fold [95% CIs 2.3-12.3] and 2.2-fold [95% CIs: 1.2-3.9] higher among FSWs who had ever been contacted by intervention staff and 5.0-fold [95% CIs: 2.5-9.8] and 2.2-fold [95% CIs: 1.3-3.9] higher among FSWs who had ever been given condoms by intervention staff, compared to those who never had been. None of the intervention exposure variables were significantly associated with CCU by the most recent repeat client in bivariate or multivariable analysis (Tables 5.1 and 5.2).

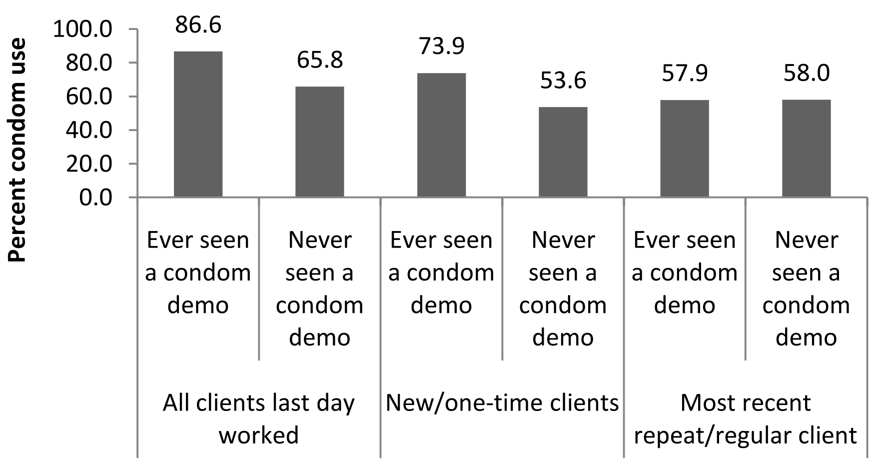
In bivariate analysis testing for trends, CCU by all clients in the most recent day worked was significantly associated with an increased duration since first contacted by intervention staff, the number of times contacted by intervention staff and the number of condom demonstrations seen by staff in the last month. CCU by occasional clients was significantly associated with an increased duration since first contacted by intervention staff and the number of condom demonstrations seen by staff in the last month. In multivariable analysis, significant tests for trends indicated a dose-response relationship between CCU by all clients in the most recent day worked and CCU by occasional clients, and increased duration since first contacted by staff ($p=0.003$, $p=0.007$ respectively). For both of these outcomes, significant tests for trends also indicated a dose-response relationship between CCU by all clients in the most recent day worked and CCU by occasional clients and increased numbers of condom demonstrations witnessed (p=0.001 and p=0.046 respectively). Finally, a dose-response relationship was also observed between CCU by all clients and number of times contacted by staff (p=0.002).

Figure 5.1: Relationship between indicators of intervention exposure and consistent condom use (CCU) by all commercial clients of female sex workers in the most recent day worked, CCU by occasional clients and CCU by repeat clients, based on the results of special behavioural surveys in Karnataka state, India, including:

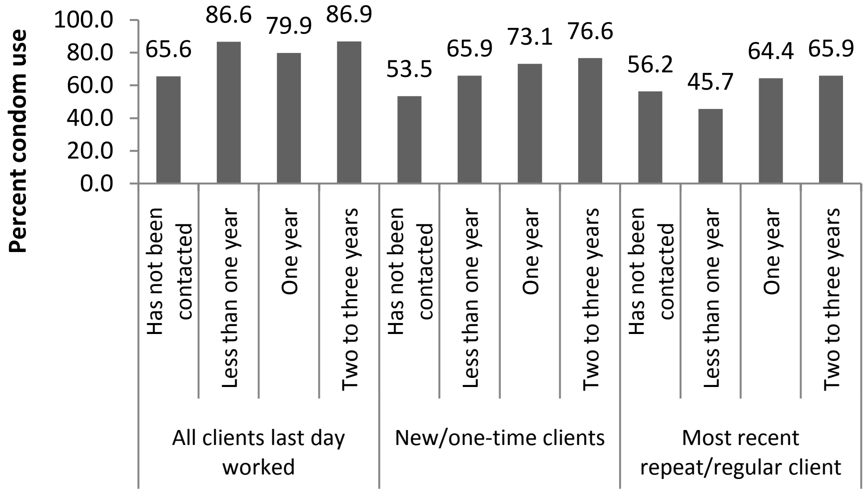
(a) CCU vs. ever been contacted by intervention staff.



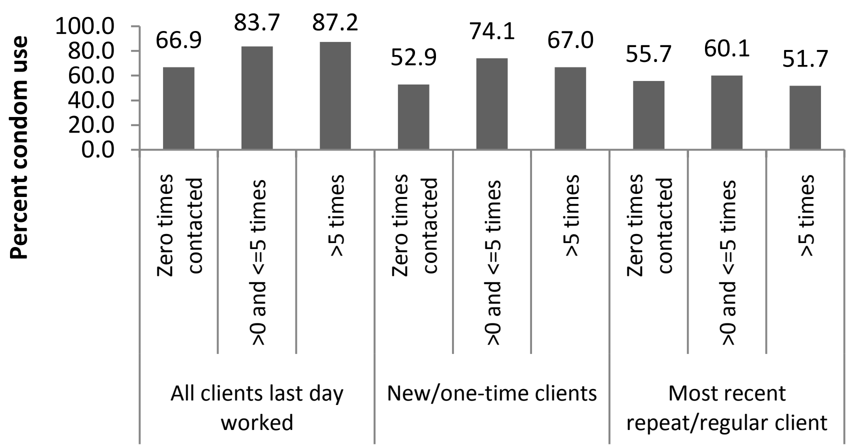
(b) CCU vs. ever seen a condom demonstration by intervention staff.



(c) CCU vs. time since first contacted by intervention staff.



(d) CCU vs. number of times contacted by staff in the past month.



(e) CCU vs. number of condom demonstrations by staff observed by female sex workers in the past month.

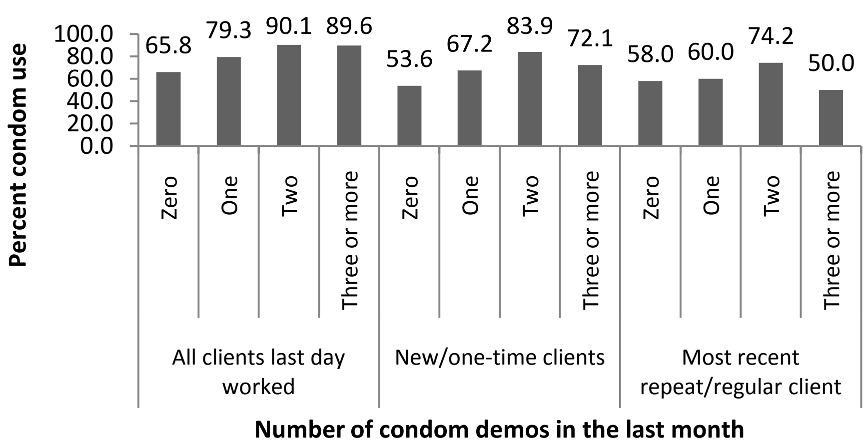


Table 5.2: Multivariable associations (adjusted odds ratios [AOR] and 95% confidence intervals [95% CIs]) between intervention exposure factors and consistent condom use by commercial partners of female sex workers in Karnataka state, India.

MODEL[1]		**OUTCOME: Consistent condom[2] use within different sex partnerships**					
		Condoms used in each occasion of sexual intercourse with clients in the most recent day worked		Consistent condom use with occasional clients		Consistent condom use with most recent repeat client	
	INTERVENTION EXPOSURE	AOR [95% CIs]	*p*	AOR [95% CIs]	*p*	AOR [95% CIs]	*p*
1	Ever contacted by intervention staff	5.26 [2.25-12.29]	<0.001	2.17 [1.22-3.87]	0.006	1.07 [0.34-3.33]	0.993
2	Had a condom demonstration by intervention staff	4.97 [2.52-9.77]	<0.001	2.20 [1.25-3.86]	0.009	0.88 [0.29-2.66]	0.812
3	Duration since first contacted by intervention staff						
	Has not been contacted	1.0 (ref)		1.0 (ref)		1.0 (ref)	
	Less than one year (greater than zero)	4.85 [2.11-11.13]	<0.001	1.67 [0.92-3.04]	0.095	0.65 [0.19-2.19]	0.487
	One year	4.25 [1.66-11.23]	0.003	2.57 [1.24-5.33]	0.011	1.53 [0.51-4.65]	0.449
	Two-three years	9.40 [3.06 -	<0.001	3.49 [1.47-8.28]	0.005	2.55 [0.79-8.23]	0.118
	Test for trends	28.94]	**0.003**		**0.007**		/
4	Number of times contacted by intervention staff						
	Zero	1.0 (ref)		1.0 (ref)		1.0 (ref)	
	Five or fewer (greater than zero)	4.38 [1.92 -9.97]	<0.001	2.53 [1.36-4.72]	0.003	1.12 [0.36-3.51]	0.847
	Greater than five	5.32 [1.56-18.07]	0.008	1.77 [0.67-4.70]	0.250	0.87 [0.21-3.60]	0.844
	Test for trends		**0.002**		/		/
5	Number of condom demos by staff seen past month						
	Zero	1.0 (ref)		1.0 (ref)		1.0 (ref)	
	One	3.64 [1.76-7.53]	<0.001	1.45 [0.71-2.93]	0.306	1.08 [0.42-2.76]	0.875
	Two	8.03 [3.17-20.34]	<0.001	4.47 [2.21-9.03]	<0.001	1.97 [0.80-4.87]	0.143
	Three or greater	4.68 [1.98-11.06]	<0.001	1.99 [1.07-3.70]	0.31	0.70 [0.21-2.35]	0.561
	Test for trends		**0.001**		**0.046**		/

[1]Models were all adjusted for variables that were included a priori and variables that were significantly associated with each outcome on the *p*<0.10-level in bivariate analysis. For all three outcomes of condom use, a priori variables included typology of sex work (place of solicitation) and district; for condoms used in each occasion of sexual intercourse with clients in the most recent day worked, models were also adjusted by marital status, having a non-commercial partner, numbers of clients in the most recent day worked, age and age at first sex; for condom use with occasional clients, models were also adjusted by age, marital status, literacy, had a non-commercial partner in the last year, age at first sex work; for condom use with repeat clients, models were also adjusted by education.
[2]Consistent condom use is defined as reporting always (100%) using condoms
/ Test for trend not significant in bivariate analysis, and was not tested in multivariable models

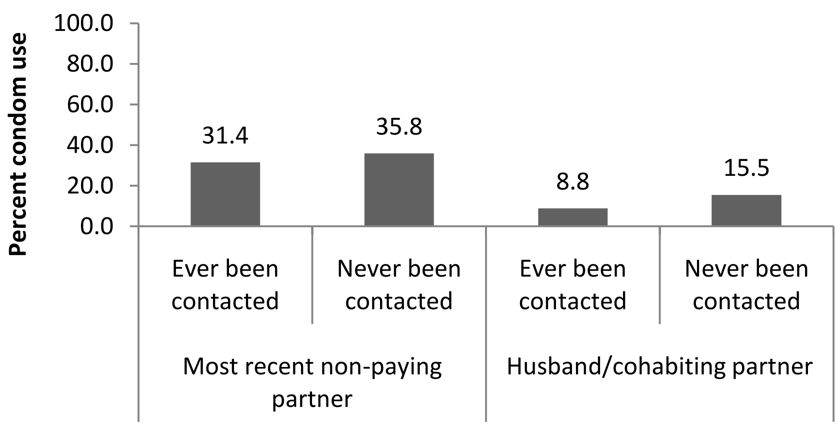
Condom use with intimate partners

Of the total sample, 226 FSWs reported having a non-paying sex partner in the last year (other than a husband/cohabiting partner) and 354 FSWs had a husband/cohabiting partner. Overall, 68 (31.1%) and 40 (9.6%) reported CCU by their most recent non-paying partner and their husband/cohabiting partner respectively (Table 5.1). In contrast to CCU by all clients and by occasional clients, CCU by their most recent non-paying partner was higher among FSWs who had never been contacted by intervention staff compared to those who had been contacted (35.8% versus 31.4%); the same was true for CCU by their husbands/cohabiting partner (15.5% versus 8.8%). CCU by their most recent non-paying partner was higher for those who had seen a condom demonstration compared with those who had not (34.0% versus 26.6%), while CCU by their husband/cohabiting partner was higher for those who had never seen a condom demonstration compared to those who had (12.9% versus 9.3%) (Figures 5.2a-5.2b). Figure 5.2c demonstrates how CCU by both types of partners decreased and then increased as the duration of time since first contacted by intervention staff increased. CCU by both their most recent other non-paying partner and by their husband/cohabiting partner decreased as the number of times contacted by staff in the past month increased (Figure 5.2d). CCU by the most recent other non-paying partner initially increased as the number of condom demonstrations witnessed increased, and then dropped by almost half for women who had seen three or more demonstrations in the past month. CCU by husbands/cohabiting partners decreased approximately steadily with increasing number of condom demonstrations (Figure 5.2e).

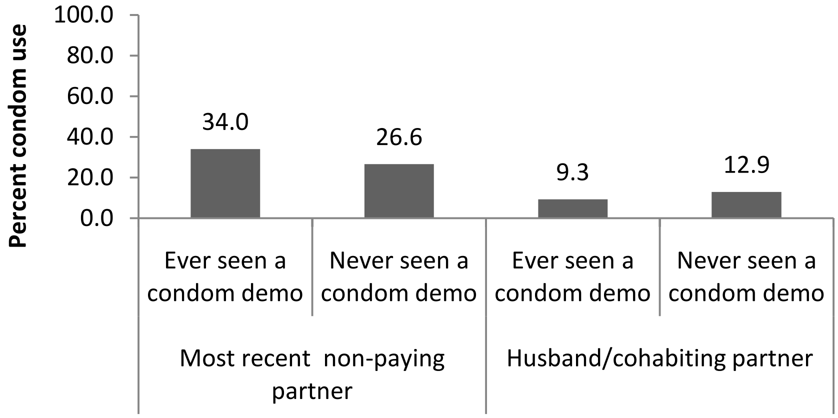
In bivariate logistic regression, only the variable, number of times contacted by intervention staff, was significantly associated with CCU by FSWs' most recent other non-paying partner (on a $p<0.10$ significance level – results not shown). In multivariable analysis, after adjusting for social and environmental factors, none of the intervention exposure variables were significantly associated with CCU by their non-paying partner or husband/cohabiting partner (Table 5.3). In bivariate analysis testing for trends, CCU by FSWs' most recent non-paying partner was inversely associated with the number of times contacted by intervention staff and CCU by their husband/cohabiting partner was inversely associated with the number of condom demonstrations by intervention staff. In multivariable analysis testing for trends, CCU by FSWs' husband/cohabiting partner remained inversely significantly associated with the number of condom demonstrations by intervention staff (p=0.05).

Figure 5.2: Relationship between indicators of intervention exposure and consistent condom use (CCU) by the most recent non-paying partner of female sex workers and female sex workers' husband/cohabiting partner, based on the results of special behavioural surveys in Karnataka state, India, including:

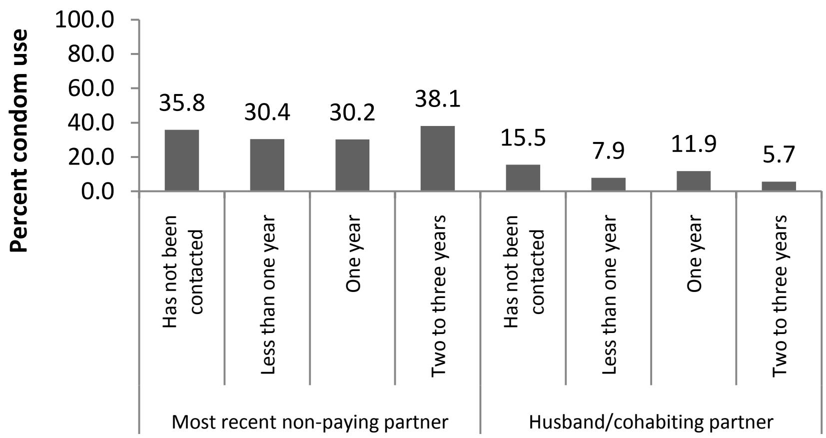
(a) CCU vs. ever been contacted by intervention staff.



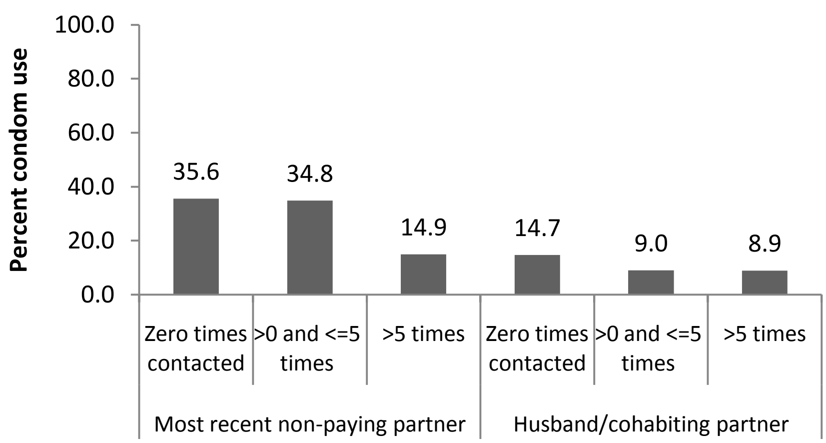
(b) CCU vs. ever seen a condom demonstration by intervention staff.



(c) CCU vs. time since first contacted by intervention staff.



(d) CCU vs. number of times contacted by staff in the past month.



(e) CCU vs. number of condom demonstrations by staff observed by female sex workers in the past month.

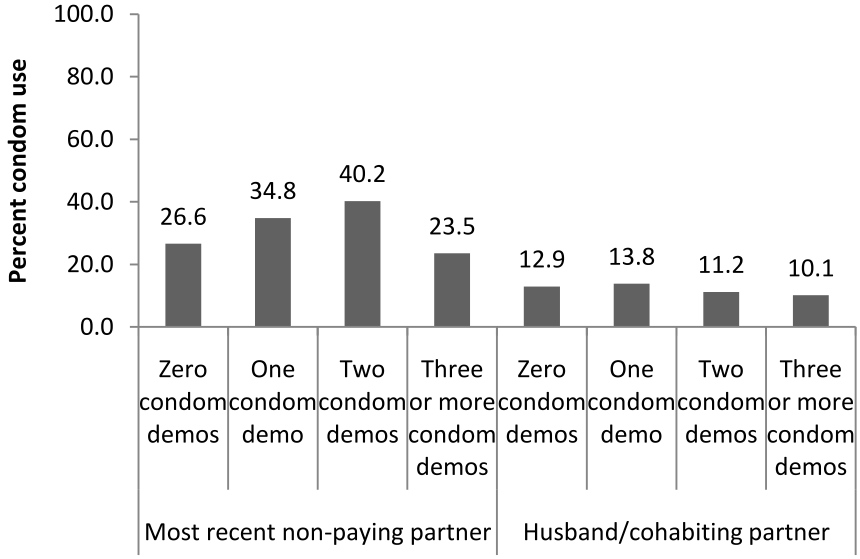


Table 5.3: Multivariable associations (adjusted odds ratios [AOR] and 95% confidence intervals [95% CIs]) between intervention exposure factors and consistent condom use with non-commercial partners of female sex workers in Karnataka state, India.

MODEL[1]	INTERVENTION EXPOSURE	OUTCOMES: Consistent condom use[2] with most recent non-paying partner AOR [95% CIs]	*p*	Consistent condom use[2] with husbands/cohabiting partners AOR [95% CIs]	*p*
1	Ever contacted by intervention staff	1.22 [0.39-3.80]	0.732	0.35 [0.11-1.16]	0.085
2	Had a condom demonstration by intervention staff	1.54 [0.52-4.57]	0.435	0.50 [0.17-1.43]	0.194
3	Duration since first contacted by intervention staff				
	Has not been contacted	1.0 (ref)		1.0 (ref)	
	Less than one year (greater than zero)	0.89 [0.27-2.89]	0.842	0.39 [0.11-1.44]	0.156
	One year	1.35 [0.34-5.32]	0.666	0.48 [0.13-1.78]	0.272
	Two-three years	2.29 [0.53-9.85]	0.265	0.20 [0.03-1.43]	0.108
	Test for trends		/		/
4	Number of times contacted by intervention staff				
	Zero	1.0 (ref)		1.0 (ref)	
	Five or fewer (greater than zero)	1.51 [0.51-4.49]	0.460	0.42 [0.13-1.36]	0.146
	Greater than five	0.41 [0.09-1.79]	0.236	0.43 [0.11-1.66]	0.219
	Test for trends		**0.146**		/
5	Number of condom demos by staff seen past				
	month	1.0 (ref)		1.0 (ref)	
	Zero	3.15 [0.83-12.03]	0.093	0.86 [0.23-3.15]	0.815
	One	3.17 [0.80-12.58]	0.101	0.64 [0.18-2.27]	0.491
	Two	0.87 [0.24-3.11]	0.825	0.33 [0.10-1.00]	0.072
	Three or greater		/		**0.045**
	Test for trends				

[1]Models were all adjusted for variables that were included a priori and variables that were significantly associated with each outcome on the *p*<0.10-level in bivariate analysis. For all three outcomes, a priori variables included district and typology of sex work (place of solicitation); for condom use with most recent other non-paying partner, models were also adjusted by number of different repeat clients; for condom use with husbands/cohabiting partners, models were also adjusted by age at first sex work.

[2]Consistent condom use is defined as reporting always (100%) using condoms

/ Test for trend not significant in bivariate analysis, and was not tested in multivariable models

5.4 DISCUSSION

The results from this analysis suggest that exposure to a large-scale HIV prevention intervention was associated with higher reported condom use among FSWs in Karnataka, India, by their commercial sex clients. After adjusting for social and environmental factors in multivariable analysis, findings from this analysis demonstrated a strong independent association between CCU by all clients in the most recent day worked and CCU by occasional clients, and five measures of intervention exposure. Moreover, a significant dose-response relationship was observed between these two outcomes and increased duration since first contacted by intervention staff and number of condom demonstrations seen by staff in the past month in multivariable analysis. There was also a significant dose-response relationship observed between CCU with all clients and the number of times contacted by staff in the past month. In multivariable analysis, intervention exposure was not significantly associated with increased CCU by FSWs' most recent repeat commercial clients, their most recent non-paying partner (excluding husbands/cohabiting partners) or their husband/cohabiting partner.

The association between increased intervention exposure and increased CCU by all clients likely reflects higher condom use by occasional clients, which constitute the majority of commercial clients of FSWs in Karnataka. On a micro-level, results indicated that condom use by occasional clients likely improved due to regular contact between FSWs and peer outreach workers (i.e., members of local sex worker communities), who were responsible for providing condoms to FSWs, giving demonstrations of correct condom use and facilitating conversations about risk and vulnerability [Managing HIV prevention from the ground up: Avahan's experience in peer led outreach at scale in India 2008]. Peers also encouraged membership in community groups and were proponents of community mobilization, which is intended to facilitate condom negotiation by FSWs and use by clients through both individual-level and collective empowerment and agency [Halli et al., 2006, Sarkar 2010]. Interestingly, CCU by occasional and repeat clients in this analysis was highest for FSWs who had seen two condom demonstrations by staff in the previous month and lower for FSWs who had seen three or more. CCU by these clients was also higher among FSWs who had been contacted <5 times compared to those who had been contacted 5+ times. These results could suggest that there may be a point where increased contact by intervention staff or education about correct condom use by staff will not improve condom use [Aral et al., 2008]. Resources may be better directed to other features of the intervention if additional increases in condom use are to be observed. CCU was found to more steadily increase with increased duration since first contacted by the intervention. This effect may not have levelled off or decreased (as with the previous two intervention exposure variables) over time due to the limited amount of time since the intervention began in some districts (varied from 1.5-2.5 years). Condom use also may have naturally increased over time in southern India (reflected in the duration since first contacted by staff) albeit likely at slower rates than in if the intervention was not present. Improved condom availability was also a key feature of the intervention [Bradley et al., 2010]. This facilitated condom use simply by increasing access, but also likely by increasing social acceptance of condoms through increased visibility and presence. Other interventions incorporating these program elements have shown success in improving condom use among FSWs [Cohen 2004, Jana et al., 2004, Kerrigan et al., 2007].

The results from this study are supported by previous mathematical modelling studies indicating that the increase in condom use after initiation of the intervention was consistent with HIV epidemiological trends in some areas of Karnataka state [Pickles et al., 2010], as well as observational studies suggesting that intervention exposure was associated with consistent condom use with male clients [Lipovsek et al., 2010] and FSWs [Ramesh et al., 2010, Reza-Paul et al., 2008] in Karnataka. There is also evidence to suggest that increased condom levels can be sustained over time in this population [Ramesh et al., 2010]. Nevertheless, continued monitoring of condom use levels and assessments of the impact of observed increases in condom use on reducing HIV and STIs is important for a long-term and comprehensive understanding of the impact of the intervention.

While CCU by all clients and occasional clients was statistically significantly associated with increased exposure to the intervention, CCU by FSWs' most recent repeat client, non-paying partner and their husband/cohabiting partner was not. However, some bivariate evidence suggests that intervention exposure also was weakly associated with CCU by repeat clients for several intervention exposure variables (duration of exposure to the intervention; number of condom demonstrations seen by staff). CCU by FSWs' husband/cohabiting partner decreased significantly with increasing numbers of condom demonstrations seen by intervention staff in the previous month. It is not clear why this was observed, but of note, CCU with FSWs' husband/cohabiting partner was very low and the absolute proportions did not vary substantially according to the number of condom demonstrations seen (10.1% to 13.8%). The reasons for condom use within these non-commercial or intimate sex partnerships of FSWs are complex. These may include power disparities that favour the male partner [Shannon et al., 2008a, Wang et al., 2007b, Wojcicki and Malala 2001], including an economic dependence on longer-term male partners [Luke 2005, Luke 2006]. The use of condoms may not be acceptable in intimate relationships, if there is greater longevity, trust and intimacy within the partnership; the use of condoms may also be perceived as a symbol of infidelity and foster mistrust [Varga 1997]. Women may agree to not use condoms with repeat clients in exchange for these partners providing a stable form of longer-term income or because they feel they can assess if their partner is not infected with HIV after they have seen him several times. Further research is required to better understand condom use with non-commercial partners of FSWs; in particular, understanding gender-based interpersonal factors that influence condom use and preferences by both partners, as well as environmental/structural elements (e.g., influencing favourable societal views of condoms) that could be incorporated into interventions to increase condom use. The female condom could play an increasing role in HIV prevention within non-commercial or intimate partnerships. In addition, recent promising findings of the effectiveness of microbicides indicate that microbicides could be an important facet of HIV prevention as an alternative to condoms for women whose non-paying partners or husbands/cohabiting partners do not use condoms [Karim et al., 2010].

There are several limitations to this analysis. The analysis is based on self-report data from cross-sectional surveys collected in three districts and is not a randomized controlled experiment study. This analysis relied on self-reported answers to questions that may be perceived as sensitive (e.g., consistency of condom use), and the questions are therefore susceptible to social desirability bias [Hanck et al., 2008]. This may have overestimated the relationship between intervention exposure and CCU, and it is possible that women with increased condom use are more likely or able to be accessed by intervention-related services and programs rather than the other way around. However, this is unlikely, since the total sample size was relatively large, particularly for a marginalized and hidden population of FSWs, and the cluster sampling design was used to make the sample as representative as possible, with complex survey methods accounting for the sampling design. Additionally, results suggest a dose-response relationship between exposure to the intervention and increased CCU within commercial partnerships. This provides more convincing evidence that the intervention had an impact on increasing CCU [Szklo and Nieto 1999].

The impact of increases in condom use among FSWs and their clients on HIV and STIs in these populations should be assessed in future studies. Large-scale HIV prevention programs designed to reduce HIV and STI prevalence among core groups could in theory also have an indirect impact on HIV prevalence within general populations [Vickerman et al., 2010]. Since many clients of FSWs have wives, as well as other FSW partners, and since condom use is low in these partnerships, clients provide an important potential transmission bridge between FSWs and the general population [Lowndes et al., 2002, Vickerman et al., 2010]. Since condom use tends to be relatively low among FSWs' repeat clients and non-commercial or intimate partnerships, these partners could also provide a transmission bridge *to* FSWs [Lowndes et al., 2000]. It is not clear if the intervention has had an impact on non-core or bridging groups. A mathematical modelling analysis was conducted to help understand the observed decline in HIV prevalence among women attending antenatal clinics from 2005 to 2007. The analysis suggested that the extent of the decline observed was unlikely to be solely attributed to the intervention implemented in FSWs. In other words, the decline in FSW HIV prevalence observed was not large enough in the short term to influence the antenatal prevalence, even if the intervention would likely be effective at reducing FSW and antenatal clinic HIV prevalence in the longer-term [Boily et al., 2008]. The impact of the intervention on non-core and bridging groups should continue to be assessed.

If the intervention's influence on condom use varies by type of commercial sex client (e.g., occasional compared to repeat clients) *and* the patterns of sexual structure vary geographically (e.g., districts such as Bangalore have higher fractions of occasional clients and lower numbers of repeat clients per month), different intervention effects across the three districts in Karnataka may be observed. CCU by non-paying partners was also much lower in Bangalore (12.8%) compared to the other two districts (45.7% and 41.6% respectively), indicating that the importance of these partnerships in this district may be more pronounced, and should be considered in this district more than others when planning interventions. Exploring the relative role of different patterns of sexual contacts between FSWs and their male partners and variation in the numbers of different types of partners on HIV transmission in Karnataka, India, using simulation studies, would be useful to further improve the impact of the intervention [Blanchard et al., 2005, Blanchard and Moses 2007, Buzdugan et al., 2009, Coffee et al., 2007, Deering et al., 2008].

Study findings suggest that the exposure to a large-scale HIV prevention intervention among FSWs was associated with increased condom use by occasional clients, with a dose-response relationship, but that it did not seem to impact condom use by repeat clients, non-paying partners and husbands/cohabiting partners. Future research should aim to understand why condom use remains relatively low by non-commercial or intimate partners and new strategies should be investigated and developed specifically to increase condom use by these partners. These strategies should go beyond education and condom promotion and address structural gender-based inequities within intimate partnerships of FSWs.

CHAPTER 6

DISCUSSIONS, IMPLICATIONS AND CONCLUSIONS

6.1 SUMMARY OF STUDY FINDINGS

The current study investigated the sexual structure of female sex workers (FSWs) and their male partners in Karnataka state, India. This study demonstrated how sexual structure affects HIV infection rates and is a critical consideration when designing prevention interventions in this setting. This study built on previous research regarding the links between HIV risk and sexual structure as well as the social and environmental factors that may influence HIV risk. Using secondary data analysis methods, this study examined data collected primarily from FSWs, as well as from their clients. Together, the research findings provide valuable insights into understanding the heterogeneity in sexual structure, and also how heterogeneity can influence HIV transmission dynamics and prevention. Study findings provide evidence that differences in sexual structure can be substantial within this study setting, and that the effectiveness of an intervention designed for FSWs varies according to their different sex partnerships (commercial clients and non-commercial/intimate partnerships). It is therefore necessary that HIV prevention planners adapt interventions that respond to local contexts.

Specifically, the analysis presented in Chapter 3 investigated the extent to which social and environmental factors were associated with the numbers of clients of FSWs, and compared observed patterns geographically. On a population-level, the numbers of clients of FSWs displayed substantial geographic variation. The most common predictors of higher numbers of clients of FSWs in multiple geographic regions were a reliance on sex work as sole income, younger age, and being single or cohabiting as compared to married. The effect of the environment in which women solicited clients varied according to geographic region, with women soliciting in brothels and public places having higher rates of clients.

The analysis presented in Chapter 4 characterized the features of the sexual structure of FSWs and their male partners across districts. Using mathematical modelling techniques, this analysis demonstrated how sexual structure influenced HIV prevalence on a population level. This analysis revealed a great degree of heterogeneity in sexual structure across three districts. Differences in population-level sexual structure helped to explain observed differences in HIV prevalence across districts. The epidemiological parameters that had the largest influence on increasing simulated HIV prevalence included the numbers of clients of FSWs, the numbers of FSWs visited by clients and the number of sex acts with repeat clients. The parameters with the largest influence on decreasing simulated HIV prevalence were a longer duration of the repeat client-FSW partnership and higher fraction of repeat clients. However, different model assumptions could produce different results and the independent impact of sexual structure parameters are difficult to assess, since many of these parameters are correlated. Increased heterogeneity in the numbers of clients of FSWs across populations resulted in a faster spread of HIV infection and/or had a (marginal to moderate) impact on increasing peak HIV prevalence, or had little impact. These results together suggested that patterns of sex partnerships between FSWs and their clients should be routinely considered as population-level indicators of HIV risk in addition to aggregate measures of the numbers of clients of FSWs.

In Chapter 5, noting this geographic heterogeneity in sex partnering patterns, this analysis examined the impact of a state-level HIV prevention intervention on condom use within different types of partnerships of FSWs. Research findings demonstrated a strong independent association between exposure to the intervention and increased condom use by occasional commercial sex clients, including dose-response relationships. Intervention exposure was not significantly associated with condom use by repeat clients or intimate/non-commercial partners. Future research should be targeted toward understanding why condom use by non-commercial partners and intimate partners remains relatively low. New strategies should be investigated and developed specifically to increase condom use with these partners while attending to features of the local contexts.

6.2 STUDY STRENGTHS AND UNIQUE CONTRIBUTIONS

This dissertation integrated social-epidemiologic approaches to understanding HIV risk [Diez Roux 2007, Rhodes 2002, Rhodes and Simic 2005] with a conceptual framework that emphasized the properties of HIV transmission dynamics on infection prevention. The current study is among the first to have examined the social and environmental factors that influence the numbers of clients of FSWs, using a multivariable statistical approach. In this study, a deterministic transmission dynamics mathematical model also was developed to examine the impact of sexual structure on HIV prevalence. Conventional mathematical models of HIV transmission between FSWs and clients often fail to incorporate data that offers insights into the interactions among social and environmental factors and their influences on risk behaviour. The current study incorporated data regarding the social and environmental context of risk behaviour of FSWs and used mathematical modelling analysis to reveal valuable insights into how sexual structure influences HIV transmission dynamics. A better understanding of social and environmental context can provide important insights into how to construct novel structural and environmental interventions to reduce HIV transmission.

Substantial geographic heterogeneity in the numbers of clients of FSWs and the sex partnering patterns of FSWs and their male partners was noted in the current study, which concurs with results observed in similar settings [Blanchard et al., 2005, Blanchard et al., 2007, Blanchard et al., 2008b, Williams et al., 2006]. Previous studies that use a mathematical modelling approach have explored the potential impact of different features of sexual structure in general populations [Hallett et al., 2007], have been more theoretical rather than grounded in empirical data [Garnett et al., 2008], and have studied other STIs (e.g., gonorrhoea or HSV2) [Ghani and Aral 2005]. The analysis presented in this study adds to these previous studies by examining the relative impact of epidemiological parameters describing sexual structure of FSWs and their male partners on HIV transmission dynamics, as well as by providing valuable insights into how these parameters could influence HIV prevalence.

6.3 LIMITATIONS

A number of limitations specific to each analysis are described in Chapters 3 through 5. Here, some additional discussion of these and other limitations are described.

The data used in each analysis was self-report data, causing questions about the accuracy and precision with which sexual activity are measured. Questions on sexual behaviour are sometimes perceived as sensitive, as this is a highly stigmatized topic. Responses to sexual behaviour questions may be subject to social desirability bias [Fenton et al., 2001]. Non-response rates can also be high and hinder the representativeness of the sample to the target population [Buvé et al., 2001, Edgardh 2000, Johnson et al., 2001, Ole-King'Ori et al., 1994]. To combat these potential biases, interviews were conducted in the local language and interviewers were trained to establish a rapport with FSWs. Interviews were conducted in locations where FSWs felt comfortable and where they were unlikely to be harassed by police.

Responses may also be affected by recall bias, or may be influenced by the wording of the question or the timeframe over which the respondent is asked to recall sexual behaviour [Catania et al., 1990, Fenton et al., 2001, Gillmore et al., 2009, Morrison-Beedy et al., 2006]. In this study, many of the important parameters (e.g., numbers of clients in the past month) were also based on retrospective data. To address these concerns, a supplementary sensitivity analysis for the analysis presented in Chapter 3 was conducted for the parameter 'numbers of clients per month', which demonstrated that the relationships between the numbers of clients of FSWs and social and environmental factors were mostly preserved regardless of the measure used. Results suggest that biases regarding question wording were minimal and that recall bias was stable across measures, if it was present.

Concerns might also be raised regarding the representativeness of the study sample. A complete sampling frame of all FSWs in southern India was not possible to construct due to the hidden and marginalized nature of sex work. Clusters of FSWs were identified based on geographic locations within districts and the various work environments of FSWs (e.g., homes, brothels or public places). The number of FSWs in each cluster was estimated and clusters were randomly sampled. Sampling weights were constructed based on the differential recruitment of FSWs from different work environments [Ramesh et al., 2008]. Despite these efforts, there are doubts about the representativeness of the sample to the larger FSW population in each district. This is, in part, because FSWs living only in urban areas were included. Previous research established that FSWs living in rural areas may have different social and cultural characteristics [Blanchard et al., 2005]. Representativeness was also difficult to assess because of the lack of a sampling frame of the larger population of FSWs. Nevertheless, the sample sizes employed in the current study were large, and the cluster sampling scheme, which incorporated several different probability sampling methods, aimed to make the sample as representative as possible. Inferences regarding study results may also be situated within the calendar time in which the data were collected from the study population. This study used data primarily from 2005 and 2007, but it would be expected that over the time of the data collection and beyond there would be some changes in the uptake of information, distribution of condoms and new community-based interventions, in addition to the scale-up of antiretroviral therapy to treat HIV-positive individuals [Dhamija et al., 2009]. There also may be changes to the study populations over time (e.g., due to migration). It is difficult to predict how these changes may affect study results. Results should continue to be updated over time and intervention efforts adjusted accordingly.

There are some limitations to the deterministic compartmental mathematical modelling approach used in this study. The simulated spread of HIV infection in a deterministic model is always the same under given assumptions for model parameters and initial conditions and does not allow for stochastic or 'random' effects to be incorporated [Mishra et al., 2011]. Deterministic models, thus, represent the average behaviour of a system. In contrast, individual-based models can account for individual sources of heterogeneity, including detailed patterns of sexual contact [Mishra et al., 2011]. The latter type of models could provide additional insights into how sexual structure influences HIV transmission dynamics in southern India. Moreover, the model parameters and initial conditions in this study were estimated from cross-sectional data collected in 2005 and most parameters were not time-updated (with the exception of condom use and parameters that necessarily varied over time to satisfy the balancing activity constraint (i.e., to keep the total number of partnerships between males and FSWs the same).

Therefore, the model does not take into account potential changes in the study population (e.g., sexual behaviour) that might have influenced HIV prevalence over time. However, the approach used was appropriate for the purposes of this study because it allowed for a broad examination of the impact of sexual structure factors on population-level rather than individual-level HIV prevalence to explain large differences in HIV prevalence across districts in southern India. The model and parameters used incorporated a large amount of heterogeneity in sexual behaviour through extensive stratifications and the model fit well to observed HIV prevalence data.

6.4 IMPLICATIONS

Potential implications and areas for future research relevant to each analysis included in this dissertation are described in Chapters 3-5. Here, several overarching insights will be offered that are derived from the project as a whole. These insights have potential implications for advancing theory and methods, and for informing intervention approaches, particularly the Avahan AIDS Initiative.

Advancing theory and methods

The study of HIV risk is increasingly being informed by theoretical models that acknowledge the importance of multiple levels of influence on risk behaviour. The 'Risk Environment Framework' has been applied extensively to understanding drug-related harms amongst individuals who use drugs, and is beginning to be applied to understanding sex work-related harms, along with gender-based approaches [Gender Analysis in Health: A Review of Selected Tools 2002, Gender and Sex Based Analysis: Resource Guide n.d., Krieger 2003, Rhodes 2002, Rhodes et al., 2008]. Mathematical models based on core group theory also hold promise, emphasizing the importance of accounting for heterogeneity to determine estimates of the probabilities of infection [Anderson and May 1991]. As the current dissertation illustrates, the combination of these two approaches potentially offers a powerful theoretical and analytical model to understand vulnerability to FSWs from HIV on multiple levels. In addition to the current dissertation, there has been recent other research that explores the combination of risk environment and core group theory approaches, albeit among drug users rather than sex workers [Strathdee et al., 2010] Adopting approaches, such as those employed in the current dissertation, could be of great benefit to those who are building an evidence base regarding the potential impacts of changes in risk environments of sex work. For example, decriminalizing sex work has been hypothesized to reduce client violence against FSWs and increase access to and use of health services and safer sex supplies (e.g., condoms) [Shannon and Csete 2010]. This structural policy change also may have broader implications for the sexual structure of FSWs, such as the numbers and types of partners of FSWs. This presents an excellent opportunity to employ the theoretical and methodological advances used in the current dissertation to assess, via mathematical modelling simulations, the potential effects on predicted HIV risk among FSWs.

Furthermore, the recent conceptualization of female sex work as a ‘complex system’ by Blanchard et al (2010), which draws on the theoretical work of Diez-Roux (2007), holds promise as a way to further integrate risk-environment perspectives and core group theories [Blanchard and Aral 2010, Diez Roux 2007]. A complex system approach would emphasize the “interdependence of heterogeneous individuals, the presence of non-linear relationships and feedback loops in the interactions between individuals and in the dynamic interplay between individuals and their environment” [Blanchard and Aral 2010]. Much more theoretical and methodological work is needed to fully realize the usefulness of this conceptual approach, although the current dissertation adds to the growing body of evidence informing complex systems approaches to HIV.

Informing intervention approaches

According to the Risk Environment Framework, explanations of HIV risk are situated within social, economic, political and physical environments and can provide novel insights in the design of prevention interventions that incorporate the creation of safer environments for FSWs, rather than relying solely on individual behaviour (e.g., condom use) to reduce HIV risk [Rhodes 2002]. For example, condom use by FSWs' non-commercial or intimate partners is rarely addressed effectively in interventions. Some interventions have improved condom use with occasional clients of FSWs [Hanenberg et al., 1994, Hogle et al., 2002, Jana et al., 2004, Jana et al., 2006, Ramesh et al., 2010, Reza-Paul et al., 2008, Rojanapithayakorn 2006], but condom use within intimate partnerships has not been a major focus of most interventions. In the current study, consistent condom use with intimate partners was demonstrated to be low, and higher condom use with these partners was not associated with increased intervention exposure. To better inform the development of interventions, future empirical studies should collect information on the size of the FSWs' intimate partner population, the sexual behaviour of intimate partners with other partners and the presence of HIV infection in intimate partners of FSWs. Condom use within intimate partnerships represents an important intervention point [Barrientos et al., 2007, Chan and Man 2002, Figueroa et al., 2007, Gorbach et al., 2006, Luke 2006, Murray et al., 2007, Voeten et al., 2007, Wang et al., 2007a]. Interventions that include a focus on condom use with intimate partners need to go beyond increasing education and access to address issues of trust within relationships, as well as power disparities that favour the male partner [Shannon et al., 2008a, Wang et al., 2007b, Wojcicki and Malala 2001]. Furthermore, such interventions must be constructed in ways that acknowledge the potential for gender-based violence [Panchanadeswaran et al., 2008 , Shannon et al., 2008a] and traditional social norms surrounding condom use [Blankenship et al., 2008, Panchanadeswaran et al., 2008 , Wojcicki and Malala 2001]. Future research should focus on elucidating the reasons for lower condom use in intimate or non-commercial partnerships of FSWs and how interventions can be tailored for these partnerships. Partner-based studies and interventions that are tailored specifically for men rather than FSWs should be investigated, to acknowledge the role of men in determining if condoms are used within these partnerships.

The development of HIV prevention interventions also should aim to include FSWs as part of the intervention planning and implementation team. One way to do this is to increase the use of peer-based intervention models. Peer-based models have been shown to be beneficial to reducing harms to FSWs in a number of settings [Deering et al., 2009, Deering et al., 2010a, Gadgil 1994, Janssen et al., 2009]. In the current study, peer-based delivery of services (e.g., condom demonstrations) was shown to be highly correlated with increased condom use with clients. Involvement of FSWs also is important in developing and creating community mobilization, collectivization and empowerment processes that have been cited as playing significant roles in HIV prevention among FSWs [Asthana and Oostvogels 1996, Blankenship et al., 2008, Jana et al., 2004]. Additional research is required to evaluate the specific benefits of peer components for FSWs, however, relative to other components. There is currently limited comprehensive evaluation of peer-based interventions for FSWs.

In addition, the results of the current dissertation reveal the importance of heterogeneity in terms of the heterogeneous composition of the population at risk. Several previous analyses have demonstrated the presence of high levels of variability in features of sexual structure of FSWs, including across geographically similar settings [Blanchard et al., 2007, Blanchard et al., 2008b, Boily 2009]. Heterogeneity in risk behaviour of FSWs has implications for understanding transmission dynamics of HIV infection among FSWs, and potentially among the general population [Boily 2009, Deering et al., 2008], particularly if there is substantial mixing with the bridge population. Future research should investigate the relative impact of different measures of heterogeneity in individuals (e.g., Gini coefficients, variance, skewness) in addition to aggregate measures for sexual structure distributions (e.g., average numbers of FSWs across different geographic regions, numbers of clients of FSWs within geographic regions) to help explain why HIV prevalence in FSWs varies substantially across populations. This would inform the development of a more comprehensive list of indicators that could help characterize population-level HIV risk. Multi-level epidemiological and mathematical modelling approaches could be useful. Reconceptualizing sex worker populations as being more heterogeneous than original formulations of core group theory permitted has been beneficial. Research that has identified 'cores within cores' (i.e., very high-risk groups of sex workers who may play a significant role in driving epidemics) [Blanchard 2009] is proving to be of utility to the development of interventions such as the Avahan AIDS Initiative. Further research is needed to better characterize and identify these sub-groups of FSWs and to better understand their role in transmission dynamics and prevention.

Other types of heterogeneity in the social organization and structure of sex work are also important to investigate and characterize. In particular, the environments in which sex work occurs (e.g., homes, brothels or public places) are diverse [Aral and St. Lawrence 2002, Buzdugan et al., 2009, Harcourt and Donovan 2005], as is evidenced by the heterogeneous work settings enumerated in the Avahan AIDS Initiative. Intersections between environmental context and individual risk behaviour may have important implications for developing interventions that are relevant to local contexts. For example, in contexts where ‘cores within cores’ exist, it may be more beneficial to tailor interventions to first identify and then address the needs of these smaller and more high-risk sub-groups of sex workers who are highly vulnerable to acquiring and transmitting infections [Blanchard et al., 2008b]. This approach may be used as a complementary strategy to ongoing population-level interventions, which have been criticized for their potential to exacerbate health disparities if used as a sole strategy to improve health [Frohlich and Potvin 2008]. Further research is required to understand if interventions tailored to specific sub-populations of FSWs would be beneficial in reducing HIV prevalence among these women as well as to the wider population of FSWs and their partners (and general populations).

Research to inform large-scale population-level interventions, such the Avahan AIDS Initiative, is challenging. Conventional study designs and features (e.g., random assignment of communities to experimental and control conditions) are unethical and/or impractical to implement in highly vulnerable populations such as FSWs [Boily et al., 2007b, Piot 2010]. A multi-level approach is therefore recommended to gain an overall understanding of an intervention’s impact [Boily et al., 2007b]. This approach is being used in the comprehensive monitoring and evaluation framework to assess the impact of the Avahan AIDS Initiative [Boily et al., 2007b]. The current dissertation used a social-epidemiologic approach to demonstrate that there were positive benefits of exposure to the intervention in terms of increased condom use with commercial clients. These results concurred with other assessments of the Avahan AIDS Initiative, which use other approaches such as mathematical modelling [Pickles et al., 2010, Williams et al., 2006]. Future research should continue to validate the results found in this and other studies over different time periods to see if positive impacts of the intervention can be sustained over time.

6.5 CONCLUSIONS

Collectively, the results from the quantitative epidemiological studies included in this dissertation described the heterogeneity in the sexual structure of FSWs and their male sex partners in southern India, characterized the factors that contribute to this heterogeneity, and elucidated how heterogeneity in sexual structure is important to the HIV epidemic and HIV prevention in this setting. Women in sex work in India and other settings globally continue to be highly vulnerable to HIV acquisition and transmission, and this vulnerability is shaped by a complex set of interrelated social and environmental factors. These factors include gender-based inequities such as those surrounding women's financial independence, cultural practices that restrict women from working outside the home and gender gaps in terms of education, literacy and employment. This highlights the importance of not relying on numbers of sex partners or condom use solely as markers of HIV risk. The heterogeneous risk faced by FSWs needs to be recognized in order to explain differences in HIV epidemics between FSW populations and launch effective, and population-specific interventions that are concurrently sensitive to local contexts and capable of addressing the complexities implied by heterogeneity.

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APPENDIX 1: SUPPLEMENTARY TABLES

LIST OF TABLES

Table A1.1: Plan of analysis for the univariate sensitivity analysis. The epidemiological parameters investigated are listed. The influences of each parameter, when varied, on other parameters in the model, are also listed.

Parameter	Epidemiological parameter	Influences on other parameters	Range varied (from baseline)
Sexual structure	Average numbers of clients per FSW per year i) Sub-populations have sub-population average (baseline) ii) Sub-populations have population average	Client population size #Visits to FSWs by clients over time	half to double
	FSW population size	Client population size	2,000 (1,000 – 4,000)
	Number of FSWs visited by clients	Client population size	6.5 (3.2-12.9)
	Fraction of repeat clients (of FSWs)	Numbers of repeat clients per FSW Numbers of occasional clients per FSW Total numbers of clients per FSW Client population size	0.35 (0.18-0.70)
	Fraction of repeat FSWs (of clients)	Numbers of repeat FSWs visited per client Numbers of occasional FSWs visited per client Total numbers of FSWs visited per client Client population size	0.17 (0.085-0.34)
	Duration of the repeat client partnership	Numbers of repeat clients per FSW Total numbers of clients per FSW Client population size	30 (15-60)
	Duration of the repeat FSW partnership	Numbers of repeat FSWs visited per client Numbers of occasional FSWs visited per client Total numbers of FSWs visited per client Client population size	30 (15-60)
	Numbers of sex acts per repeat client	Transmission probabilities	54 (27-114)
	Number of sex acts per occasional client	Transmission probabilities	1 (1-3)
	Duration of sex work (years)	Population growth rate	10.5 (5.3-21)
	Duration of being a client (years)	Population growth rate	8.5 (4.3-17.0)
	Fraction of FSWs with a main intimate partner	Intimate partner/ client population size	0.52 (0-100)
	Number of sex acts with main intimate	Transmission probabilities	1.2 (0.6-2.4)
	Number of intimate partners that FSWs currently have	Intimate partner/ client population size	92 (46-184)
Condom use	Always use condoms with occasional clients[1]	Transmission probabilities	10% reduction to 10% increase
	Always use condoms with regular clients[1]		20% reduction to 20% increase
	Always use condoms w/ main intimate partner[1]		20% reduction to 20% increase

Table A1.2: Impact of varying certain sexual structure parameters on other population-level measures of sexual structure.

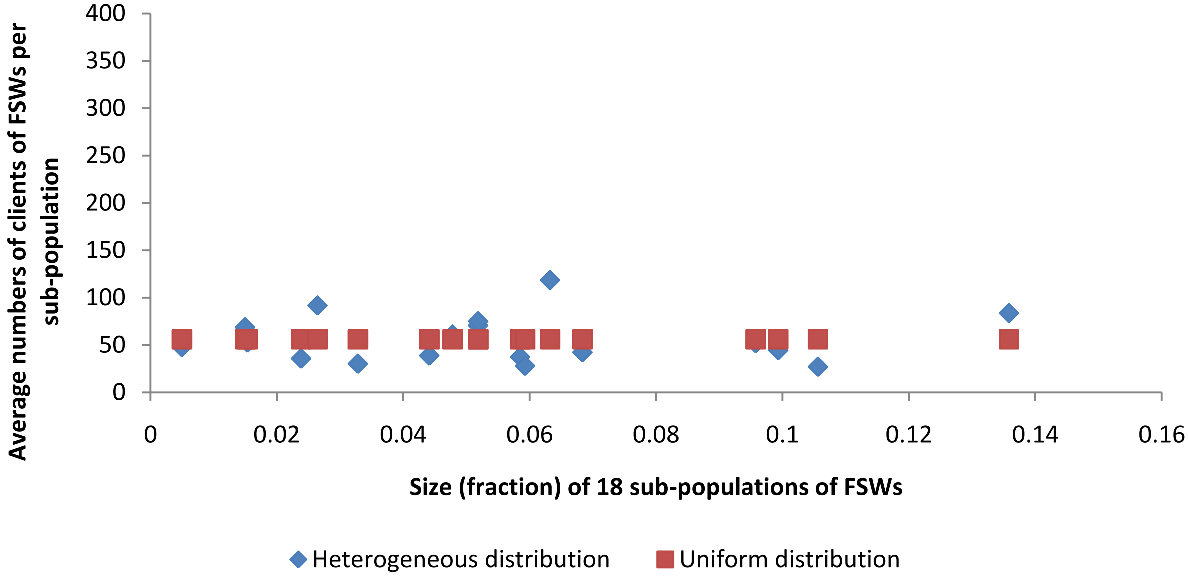
Parameter varied	Total numbers of clients per month	% repeat clients of last ten	Duration of repeat client partnerships (months)	# occasional clients per year	# repeat clients per year	Total # clients per year	Size of FSWs	Total # FSWs per client per six months	% repeat FSWs	Duration of repeat client partnerships (months)	# occasional FSWs per year	# repeat FSWs per year	Total # FSWs per year	Size of client population
Duration of repeat client partnership	57.00	0.35	15	444.60	3.99	448.59	2000	3.60	0.17	30	5.98	0.49	6.47	138762
	57.00	0.35	30	444.60	2.00	446.60	2000	3.60	0.17	30	5.98	0.49	6.47	138145
	57.00	0.35	60	444.60	1.00	445.60	2000	3.60	0.17	30	5.98	0.49	6.47	137836
Duration of repeat FSW partnership	57.00	0.35	30	444.60	2.00	446.60	2000	3.60	0.17	15	5.98	0.98	6.96	128420
	57.00	0.35	30	444.60	2.00	446.60	2000	3.60	0.17	30	5.98	0.49	6.47	138145
	57.00	0.35	30	444.60	2.00	446.60	2000	3.60	0.17	60	5.98	0.24	6.22	143581
Fraction of repeat clients	57.00	0.17	30	567.72	0.97	568.69	2000	3.60	0.17	30	5.98	0.49	6.47	175912
	57.00	0.35	30	444.60	2.00	446.60	2000	3.60	0.17	30	5.98	0.49	6.47	138145
	57.00	0.70	30	205.20	3.99	209.19	2000	3.60	0.17	30	5.98	0.49	6.47	64709
Fraction of repeat FSWs	57.00	0.35	30	444.60	2.00	446.60	2000	3.60	0.09	30	6.59	0.24	6.83	130721
	57.00	0.35	30	444.60	2.00	446.60	2000	3.60	0.17	30	5.98	0.49	6.47	138145
	57.00	0.35	30	444.60	2.00	446.60	2000	3.60	0.34	30	4.75	0.98	5.73	155847

APPENDIX 2: SUPPLEMENTARY FIGURES

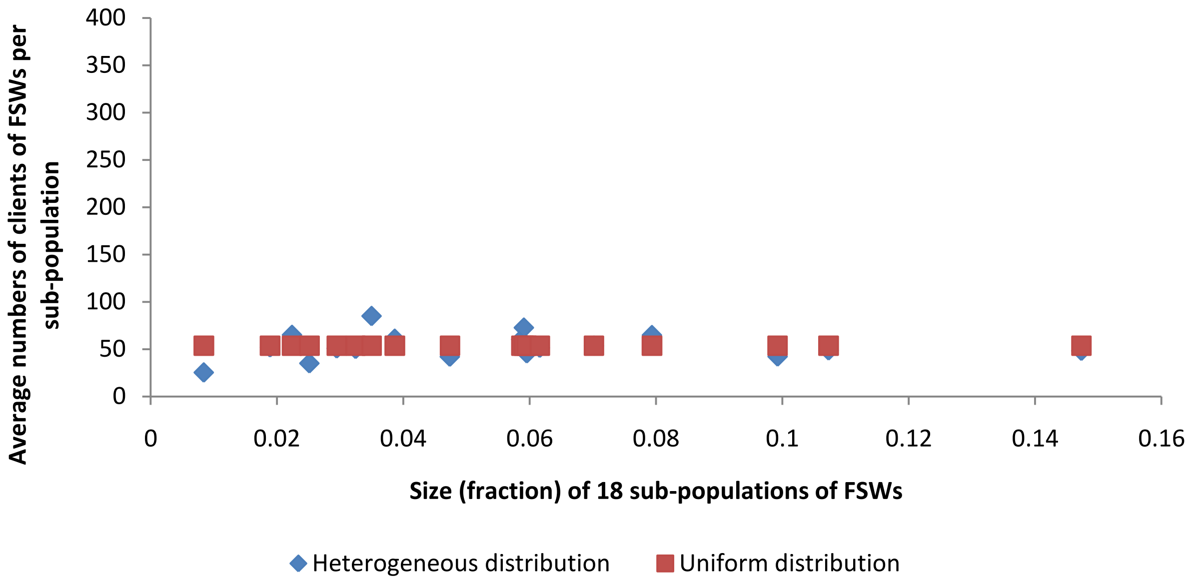
LIST OF FIGURES

Figure A2.1: Heterogeneous (sub-populations have sub-population averages) and uniform (sub-populations have population averages) distributions of the numbers of clients of FSWs from districts in Karnataka state, southern India, including:

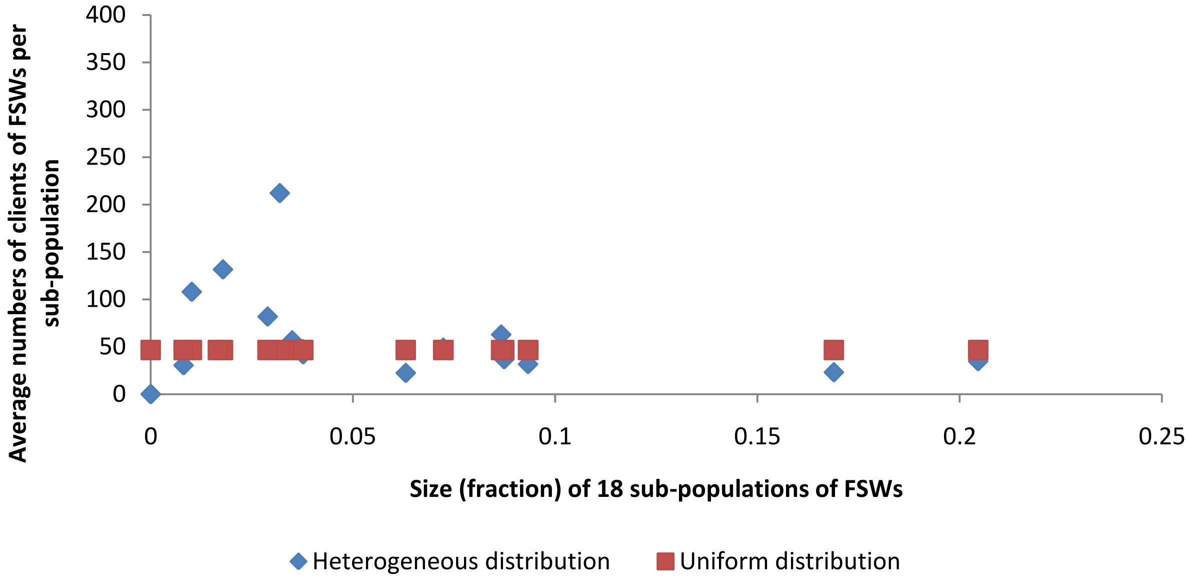
(a) Distributions from Belgaum 2005.



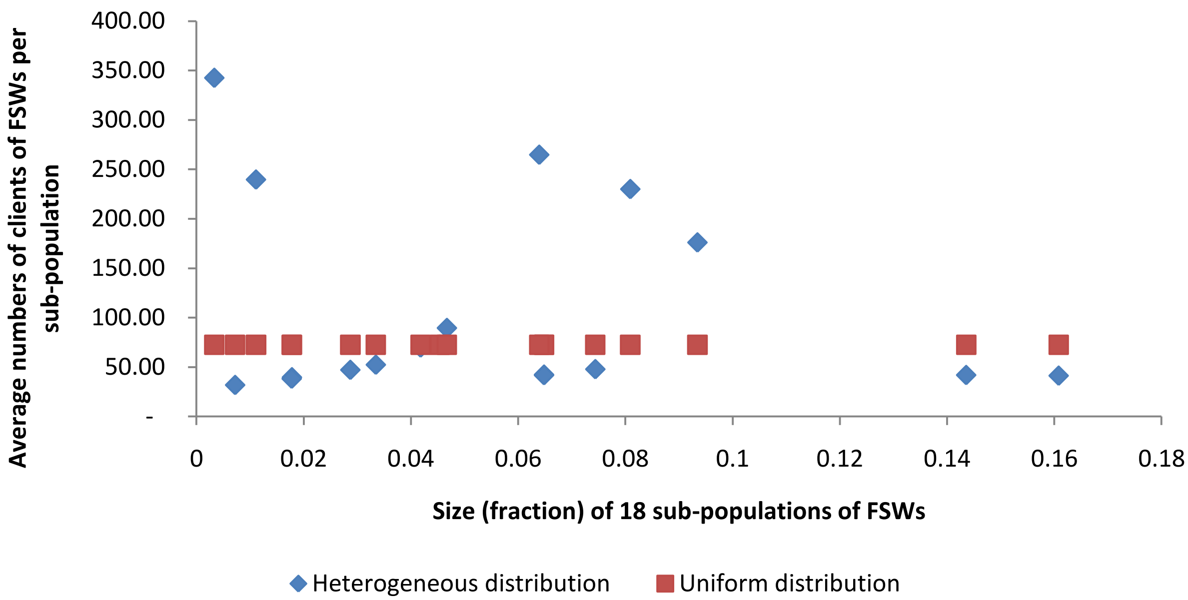
(b) Distributions from Belgaum 2007.



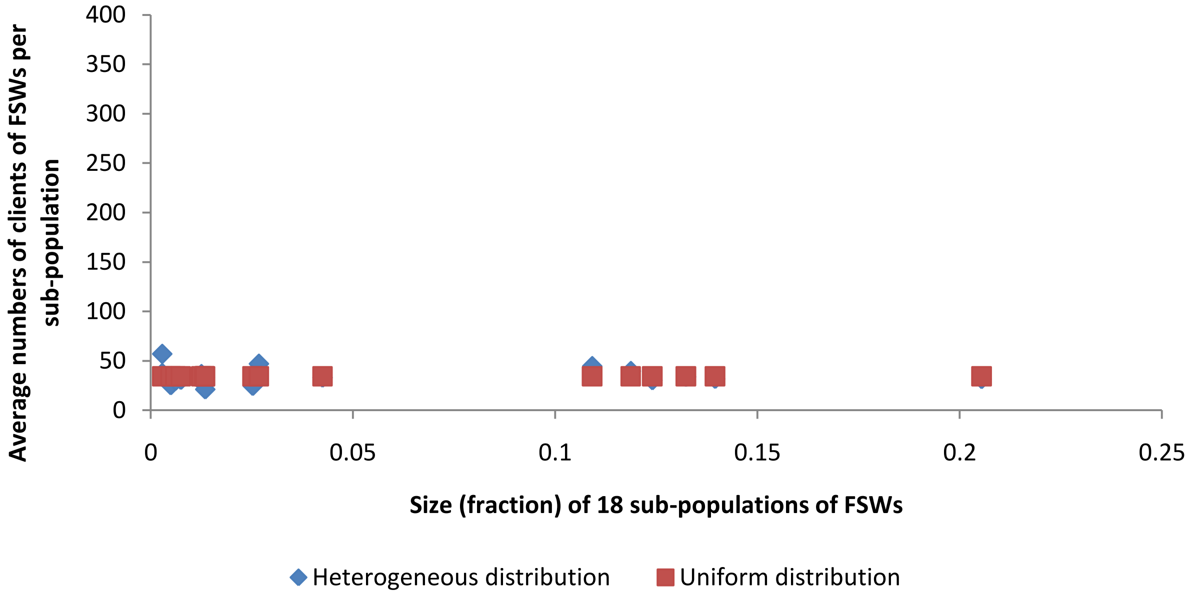
(c) Distributions from Bellary 2005.



(d) Distributions from Bellary 2007.



(e) Distributions from Bangalore 2005.



(f) Distributions from Bangalore 2007.

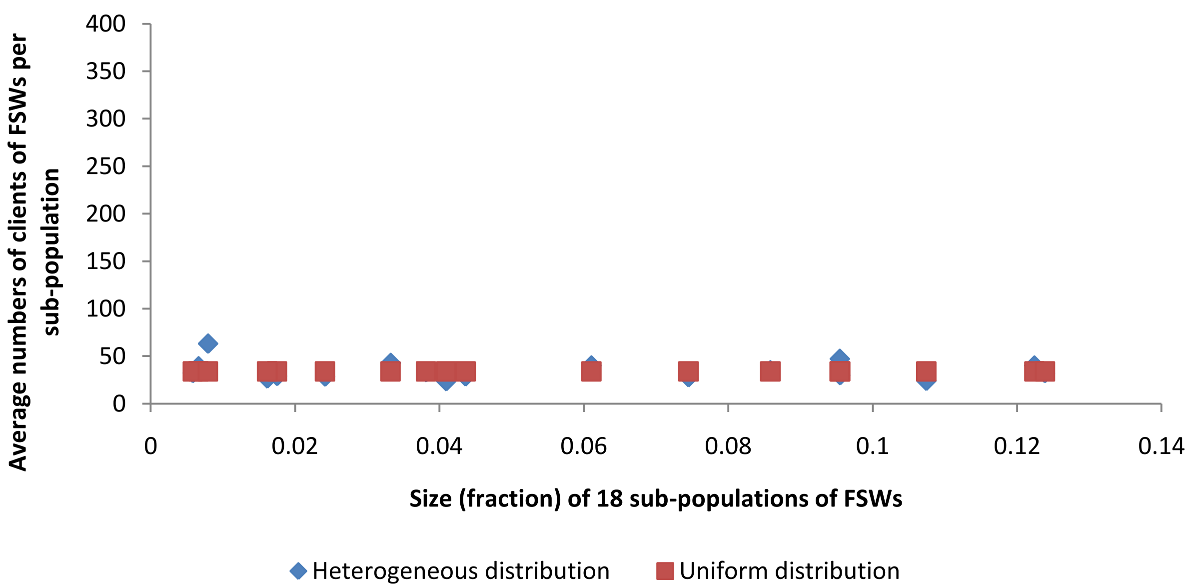


Figure A2.2: Condom use with different types of male sex partners over time.

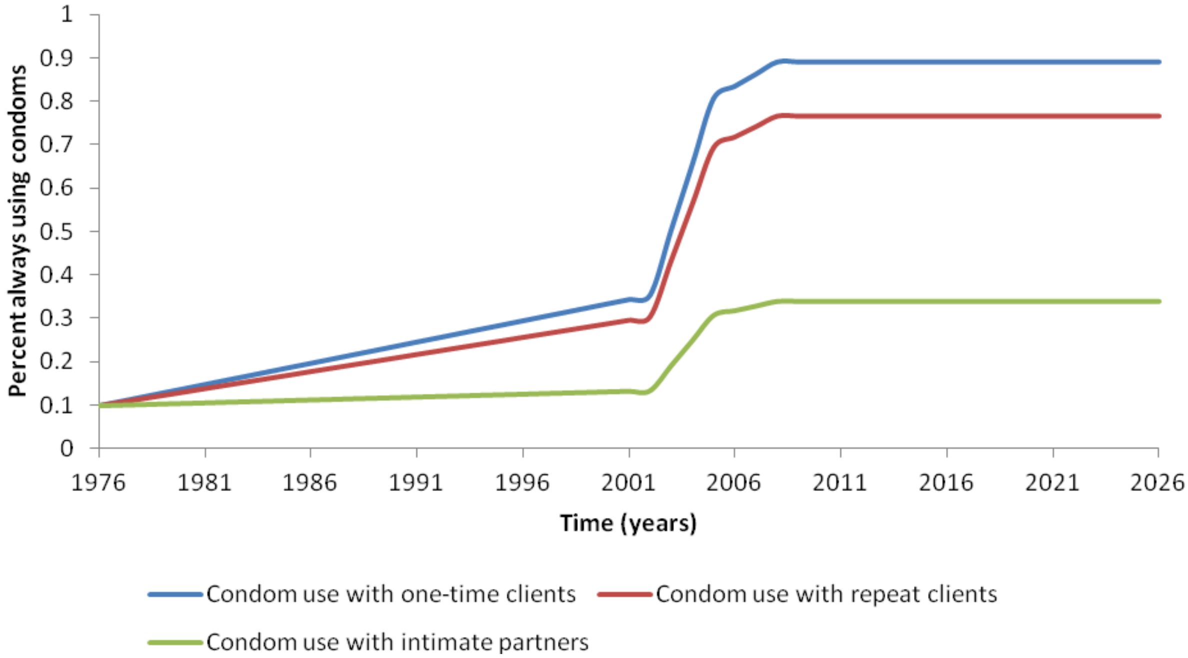
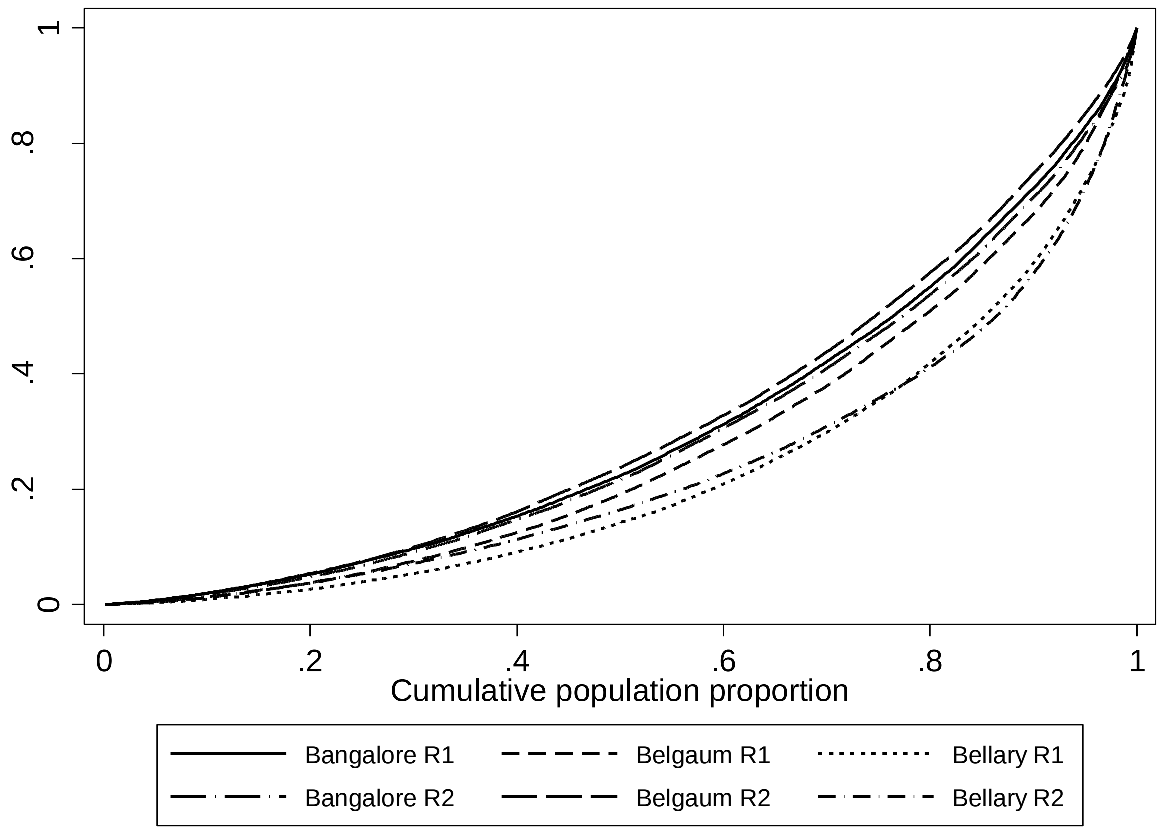


Figure A2.3: Lorenz curves for the numbers of clients per month by district and round.



APPENDIX 3: MODEL DETAILS AND OTHER CALCULATIONS

HIV/STI model equations

The model is represented by a set of deterministic ordinary differential equations, which are solved numerically using Berkeley Madonna software. The equations for HIV transmission over time are summarised as follows:

$$\frac{dX_{kj}^{0r}(t)}{dt} = B_k N(t) - \lambda_{kj}(t) X_{kj}^{0r}(t) - (\varepsilon_k + \mu_k) X_{kj}^{0r}(t)$$

$$\frac{dX_{kj}^{1r}(t)}{dt} = \lambda_{kj}(t) X_{kj}^{1r}(t) - \gamma^1 X_{kj}^{1r}(t) - (\varepsilon_k + \mu_k) X_{kj}^{1r}(t)$$

$$\frac{dX_{kj}^{2r}(t)}{dt} = \gamma^1 X_{kj}^{1r}(t) - \gamma^2 X_{kj}^{2r}(t) - (\varepsilon_k + \mu_k) X_{kj}^{2r}(t)$$

$$\frac{dX_{kj}^{3r}(t)}{dt} = \gamma^2 X_{kj}^{2r}(t) - \gamma^3 X_{kj}^{3r}(t) - (\varepsilon_k + \mu_k) X_{kj}^{3r}(t)$$

$$\frac{dX_{kj}^{4r}(t)}{dt} = \gamma^3 X_{kj}^{3r}(t) - (\phi + \varepsilon_k + \mu_k) X_{kj}^{3r}(t),$$

Where:

- $X_{kj}^{hr}(t)$ represents the population (over time) of HIV infection status *h* (0=susceptible; 1=infected stage 1; 2=infected stage 2; 3=infected stage 3; and 4=infected stage 4), intimate partner status *r* (has an intimate partner versus does not have an intimate partner), gender *k* and sub-population strata *j* (by work environment, sex work as sole income and marital status; *j*=0 for all males and 1,...,12 for females).
- B_{kj} is the constant entry rate into the sexually active population, by gender *k* and sub-population *j*. Newly sexually active individuals are assumed to be uninfected. *N(t)* is the total population size at time *t*.

$$B_k = (\mu_k + P + \varepsilon_k) * r_{kk'}, \qquad \text{(A3.1)}$$

Where μ_k represents the natural death rate by gender k, *P* represents the overall population growth rate as estimated by the Indian census, ε_k represents the duration that individuals behave as either sex workers or as clients (years) and $r_{kk'}$ represents the male-to-female or female-to-male population ratio.

- $\lambda_{kj}^{r}(t)$ represents the force of infection at time *t* due to HIV for intimate partner status *r*, gender *k* and sub-population strata *j*.

  $\lambda_{kj}^{r}(t)$, for a sub-population of intimate partner status *r*, gender *k* and sub-population strata *j*, interacting with partners of intimate partner status *r'* (i.e., 1=has an intimate partner; 2=does not have an intimate partner), can generically be written as:

$$\lambda_{kj}^{r}(t) = \sum_{r'=1}^{2} (m_{kj}^{r} * (f_{kk'}^{r} * \delta_{kk'j}^{rr'} * E_{kk'j}^{r'}(t)), \qquad \text{(A3.2)}$$

Where m_{kj}^{r} is the total number of sex partners that an individual of intimate partner status *r*, gender *k* and sub-population strata *j* has (of note, *m* varies over time for clients but is constant over time for female sex workers), $f_{kk'}^{r}$ is the fraction of the total number of sex partners that are with occasional clients, repeat clients or intimate partners, for an individual of intimate partner status *r* and gender *k* with an individual of gender *k'*, $\delta_{kk'j}^{rr'}$ is the probability that an individual of intimate partner status *r* and gender *k* will have a sexual relationship with an individual of intimate partner status *r* and gender *k'*, and $E_{k'jT}^{r'}(t)$ is the exposure over time to an individual of intimate partner status *r'* and gender *k'*, sub-population strata *j*, according to the type of partnership *T* (*T*=occasional client, repeat client or intimate partner). The type of partnership is important because this determines the transmission probabilities per partnership, since:

$$E^{r'}_{k'jT} = \sum_{h=1}^{3} \beta^{h}_{kT'} X^{hr'}_{k'j}(t) \qquad \text{(A3.3)}$$

The per-partnership transmission probabilities were estimated using the following equation. The per-act transmission probabilities, both male to female and female to male, were estimated from the literature, and are the same as used in Pickles et al (2010) [Pickles et al., 2010]. These are detailed in Table 4.1:

$$\beta^{x'}_{kT} = 1 - (1 - \kappa * \pi^{x'}_{k} * \delta * p^{x'}_{k})^{N_T} \qquad \text{(A3.4)}$$

where $p^{x'}_{k}$ is the probability of transmission per act depending on the gender of the person *k* and the stage of infection of the partner (which is included in the index *x'*); *N* is the number of acts in the partnership while the partner is infected in stage *x'* (assumed to be the same at all infection stages), for a partner of type *T* (occasional client, repeat client or intimate partner – see Table 4.1), κ is the effectiveness of condoms per act at preventing infection against HIV; π is the proportion of acts for which a condom is used, depending on the type of partnership and the level of condom use of the sex worker if the partnership is commercial.

- γ^{h} , where h=1,...,3 represents the rate at which individuals move from one infection stage to the next, and is equal to the inverse of the average duration of time spent in each stage (Table 4.1).
- ϕ represents the death rate due to AIDS.

Detailed model structure

The following behavioural stratifications were used in the model, as detailed in Figure S1: FSWs were stratified by typology (whether they solicit from home, brothels or public places), by if they did sex work as their sole income or if they had other paid work, and by their marital status (married versus single, which includes divorced/separated/widowed or unmarried women, and could include women who were cohabiting with their partners); clients were not stratified by any behavioural parameters. Upon ceasing to sell/buy sex FSWs and clients return to the general population at a rate inversely dependent on the average population-level duration of sex work or duration of client behaviour, and are replaced by uninfected new FSWs/clients from the general population to maintain the proportion of the general population who are high-risk. This relatively complex structure was chosen in order to capture heterogeneity in the numbers of clients per FSW, and because in other research simpler models tested during the development stage were found to possess insufficient heterogeneity to reproduce the rapid initial rise in HIV prevalence among FSWs [Pickles et al., 2010].

New individuals were assumed to enter the susceptible population at a recruitment rate equivalent to the sum of those leaving the model through ceasing sex, mortality plus the growth rate of the population.HIV infection was modelled with a high viraemia phases during initial infection (Stage 1) and in the infection stage occurring shortly before developing AIDS (Stage 3), with a longer stage with lower infectiousness between these two stages (Stage 2). Infected infectees progress from primary to asymptomatic to pre-AIDS stages at rates from literature.

The fraction of sex acts protected by condoms was approximated by the fraction of consistent (100%) condom use. This may be an underestimate of the total fraction of sex acts protected by condoms, as it does not take into account infrequent condom use. Consistent condom use among clients was assumed to be the same as among FSWs. As described in Pickles et al 2010 [Pickles et al., 2010], it was assumed in this analysis that consistent condom use increased since the start of the HIV epidemic. It was assumed that at the beginning of the HIV epidemic (i.e., 1976), the fraction of FSWs who reported using condoms consistently was approximately 10%, increasing to 35.4% with occasional clients in 2002 (prior to the Avahan intervention). By 2005, consistent condom use with occasional clients was assumed to increase to 80.7% and in 2008 to 89.1%, where it was assumed to remain constant over time (due to lack of availability of data and potential saturation of coverage). The proportion of consistent condom users amongst was modelled to vary linearly between these discrete times. This was based on data used to reconstruct condom use over time [Bradley et al., 2010]. From 2002 on, it was assumed that condom use with repeat clients and intimate partners was reduced relative to occasional clients, according to a multiplicative factor displayed in Table 4.1.

Relationships between FSWs and clients were assumed to be either occasional (assumed to last one sex act per partnership), repeat or intimate partnerships. Proportionate mixing for each type of partnership was assumed in this analysis. The number of FSW partners (intimate or commercial) per each type of male partner over time was dependent on the size of the FSW population, the constant number of male partners per FSW (numbers of clients per FSW per year or numbers of intimate partners per FSW per year), and the size of each male population. The total number of partnerships satisfied the model activity constraint that the number of partnerships that FSWs had with males must equal the number of partnerships that males have with FSWs (Equation 4.2 and below). This equation can be comprised of individual variables that are static (e.g., population sizes and numbers of partners in one year), or over individual variables that vary over time. In the model, the population sizes changed over time, as did the number of FSWs visited by clients per year, while the numbers of clients per FSW were constant over time. The constant number of clients per FSW per year was assumed to be different for sub-population of FSWs in the baseline parameter set. Thus, the numbers of partnerships that clients had with FSWs and that FSWs had with clients were balanced and varied over time.

$$PopSize_{Client} * M_{Client} = PopSize_{FSW} * M_{FSW} \qquad \text{(A3.5)}$$

Key calculations for correlated sexual structure parameters

Population sizes of FSWs, clients and intimate partners of FSWs

Population sizes for FSWs were estimated using enumeration data. To calculate the estimated size of the client population by an indirect method, by triangulation, Equation A3.5 was used. There is very little information on FSWs' intimate partners, in terms of sexual behaviour or population sizes. To estimate a very approximate population size of FSWs' intimate partners, an indirect approximate method was again used. In the baseline district, 52.4% of FSWs reported having intimate partners. FSWs with intimate partners reported having an average of 1.4 intimate partners, with an average duration of 9.5 years for their most recent relationship. Since the average duration of these relationship was within the range of the duration of sex work, it was assumed that FSWs would have their intimate partners as sex partners for the duration of their time in sex work – thus, for a population size of 2000 FSWs (as in the baseline district), it was expected that approximately 1,467 men to be intimate partners of FSWs in 2005. It was assumed that each of these men had only one intimate FSW partner. It was assumed that a fraction of these men were also clients of FSWs. Given the lack of data available, this fraction was estimated from the fraction of FSWs who reported that their intimate partners had other

FSW partners, though this is likely an underestimate. For all populations, the population sizes at the start of the epidemic were estimated using the following equation:

$$FSWpop_{1976} = FSWpop_{2005} * e^{(-P*(2005-1976))} \qquad \text{(A3.6)}$$

Numbers of one-time clients of FSWs per year

The values of many sexual structure parameters were dependent on one another. The calculations presented here are intended to help explain why varying one sexual structure parameter influenced HIV prevalence in the model as observed (Tables A1.1 and A1.2).

The average numbers of one-time clients of FSWs per year ($M_{FSW\_one\_yr}$) was proportional to the average numbers of all clients of FSWs per month ($M_{FSW\_all\_mon}$) (which was available from the data), the fraction of clients reported of the last 10 that were occasional ($fract_{occ}$) and the number of months in a year (12).

$$M_{FSW\_one\_yr} = M_{FSW\_all\_mon} * fract_{occ} * 12 \qquad \text{(A3.7)}$$

Thus, if FSWs reported 50 clients per month, and had 70% occasional clients (and 30% repeat clients), they would have an average of 420 occasional clients per year (as opposed to 600 if all of their clients were occasional).

Numbers of repeat clients of FSWs per year

The numbers of repeat clients of FSWs per year ($M_{FSW\_rep\_yr}$) was proportional to the average numbers of all clients of FSWs per month ($M_{FSW\_all\_mon}$) (which was available from the data), the fraction of clients reported of the last 10 that were repeat ($fract_{rep} = 1 - fract_{occ}$) and the number of months in a year (12). So that the numbers of repeat clients were not overestimated, this parameter was also inversely proportional to the duration of the repeat client partnership

(dur_{rep_cli}) and directly proportional to a per-month correction factor (which re-scaled the available parameter, ‘clients per month’, to per week).

$$M_{FSW\_rep\_yr} = M_{FSW\_all\_mon} * corr * fract_{rep} *12 *1/(dur_{rep\_cli}) \quad (A3.8)$$

Using the example above, if the fraction of occasional and repeat clients were not taken into account, and all clients were assumed to be occasional, it would have been assumed from the ‘clients per month’ measure that FSWs had 600 occasional clients per year (50 clients per month*12 months). Taking into account the fraction of occasional and repeat clients, FSWs could have a maximum of 180 repeat clients per month (if repeat clients were also one-time instantaneous partnerships). But because repeat client partnerships, by definition, last for a longer period of time (approximately 30 months in Belgaum), FSWs have fewer repeat clients.

If the correction factor was not taken into account, then in this example, FSWs would have an average of 6 repeat clients per year (50*0.3*12*1/30), and 420 occasional clients. The correction factor accounts for the fact that the fraction of repeat and occasional clients is estimated out of the last 10 clients, not the last 50 clients (i.e. the fraction of repeat and occasional clients in about one week as compared to one month). Since the repeat client relationship is years long, the few repeat clients that FSWs see in one week are likely the same clients they see over the entire month. The equation then does the following calculations: the 50 total clients per month is rescaled to a per-week measure, the fraction of repeat clients is applied to get the total estimated number of repeat clients per week, this is multiplied by 12/30 months to get an approximate per-year measure (necessary for the model) – thus, the average number of different repeat clients per year is estimated to be 1.5 (i.e., they see 6 repeat clients over 2.5 years. Of note, the same value would be obtained if 50 clients per month was re-scaled to per week (12.5), this value was multiplied by the fraction of repeat clients (0.3), and then this value (3.75) was divided by 2.5 years (or 30 months). The former method allowed the analysis to use the actual data that were available.

The equations for calculating the numbers of occasional and repeat FSWs visited by clients per year are the same as above – except that data were available for the total numbers of FSWs visited by clients in six months and the fraction of FSWs who were occasional and repeat FSWs was calculated for all of the FSWs visited in the past six months (since clients visit few FSWs). Since no data were available on the average duration of the repeat FSW partnership as reported by clients, it was assumed to be the same as reported by FSWs.

Estimating the Gini Coefficient

In this study, the Gini coefficient was defined based on the fastgini function in Stata Version 10.1. Gini coefficients and Lorenz curves were outputted based on this function. The Gini coefficient, G, was calculated using the following equation:

$$G = 1 - 2 * \frac{\sum_{i=1}^{i=N} W_i * \left(\sum_{j=1}^{j=i} W_i * X_i - W_i * X_{i/2} \right)}{\sum_{i=1}^{i=N} W_i * X_i * \sum_{i=1}^{i=N} W_i}, \qquad \text{(A3.6)}$$

where observations are sorted in ascending order of X. The Stata download information for this function can be found from: http://ideas.repec.org/c/boc/bocode/s456814.html. Lorenz curves were calculated using the glcurve function in Stata.