


Multilevel Dynamic Systems Affecting Introduction of HIV/STI Prevention Innovations Among Chinese Women in Sex Work Establishments

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Abstract

Social and public health scientists are increasingly interested in applying system dynamics theory to improve understanding and to harness the forces of change within complex, multilevel systems that affect community intervention implementation, effects, and sustainability. Building a system dynamics model based on ethnographic case study has the advantage of using empirically documented contextual factors and processes of change in a real-world and real-time setting that can then be tested in the same and other settings. System dynamics modeling offers great promise for addressing persistent problems like HIV and other sexually transmitted epidemics, particularly in complex rapidly developing countries such as China. We generated a system dynamics model of a multilevel intervention we conducted to promote female condoms for HIV/sexually transmitted infection (STI) prevention among Chinese women in sex work establishments. The model reflects factors and forces affecting the study's intervention, implementation, and effects. To build this conceptual model, we drew on our experiences and findings from this intensive, longitudinal mixed-ethnographic and quantitative four-town comparative case study (2007-2012) of the sex work establishments, the intervention conducted in them, and factors likely to explain variation in process and outcomes in the four towns. Multiple feedback loops in the sex work establishments, women's social networks, and the health organization responsible for implementing HIV/STI interventions in each town and at the town level directly or indirectly influenced the female condom intervention. We present the conceptual system dynamics model and discuss how further testing in this and other settings can inform future community interventions to reduce HIV and STIs.

Keywords

China, HIV/STI prevention, multilevel intervention, system dynamics model, women sex workers

Over 30 years of HIV prevention research has demonstrated the need to take an ecological approach in order to understand and address the complex, layered factors that can both generate and eliminate the epidemic globally and locally (Evans & Lambert, 2008; Hawe, Shiell, & Riley, 2009; Latkin, Weeks, Glasman, Galletly, & Albarracin, 2010; Schensul & Trickett, 2009; Trickett, 2005; Trickett et al., 2011). Effective interventions aimed at reducing high-risk behavior, such as having unprotected sex with multiple partners or sharing syringes and other drug injection paraphernalia, must include strategies to address the broader social, political, and environmental context in which these risk behaviors occur (Latkin et al., 2010; Trickett et al., 2011).

Social and public health scientists are increasingly interested in applying system dynamics theory to improve understanding of and to harness the forces of change within complex, multilevel systems that have an impact on intervention implementation, effects, and sustainability (Foster-Fishman &

Behrens, 2007; Hawe et al., 2009; Hirsch, Levine, & Miller, 2007; Homer et al., 2010; Latkin et al., 2010; Meadows, 2008; Trickett et al., 2011). System dynamics modeling offers great promise for examining and addressing persistent problems like HIV and other sexually transmitted infection (STI) epidemics.

System dynamics models designed to explain or predict complex social change processes have been generated theoretically, quantified, and tested computationally through multiple-iteration simulations to emerge with a best fit theory

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of how changes in the testable components affect the system behavior as a whole (Hirsch, Homer, Evans, & Zielinski, 2010; Homer et al., 2010; Richardson, 2011). Models have also been developed through collaborative or participatory processes with stakeholders to identify components, assign values, and test them, with occasional confirmation and adjustment through input from stakeholders (Hovmand et al., 2012; Stave, 2002). A third approach to system dynamics model building is to use a mixed-method, ethnographic case study approach to document and describe in detail the contextual factors and processes that appear to interact and make a difference in a particular real world setting and then to test it in the same or different settings (Hawe et al., 2009). This approach has the advantage of using empirical data to systematically identify and measure these processes in real time and to examine the change factors and dynamics synchronously.

Our international research team conducted a four-site comparative case study (2007-2012) to develop and test a multilevel HIV prevention intervention in southern China. We did not initially conceptualize the study or intervention model using a system dynamics framework. A multilevel ecological model, focused primarily on linear associations among factors in the contexts inside sex work establishments, guided our intervention design and methodological approach. Analyses based on that approach, presented elsewhere (Liao, Weeks, Wang, Nie, et al., 2011; Liao, Weeks, Wang, Li, et al., 2011; Nie et al., 2013; Weeks, Liao, et al., 2010), indicated some successes in reducing sexual risk in the target population of women working in sex work establishments in the four study towns and also demonstrated important differences across study sites in intervention processes and outcomes.

Our very different experiences in the four towns and iterative analyses of our study findings led us to recognize the need to reconceptualizing our analytical model, taking into account the multidirectional forces and feedback systems in the communities outside the establishments, as well as dynamics inside the establishments, that shaped the context of risk and implementation of our intervention. On the basis of this emergent perspective and using our multisite comparative experience and our ethnographic and quantitative study findings, we have derived a model of the interactive factors and system dynamics evident in shaping the study's intervention implementation processes and outcomes. We present and illustrate this model here and discuss how this reconceptualization and further testing of the systems model in this and other contexts can inform future community interventions to reduce HIV and other STIs.

Multilevel Intervention to Reduce HIV/STI Risk Among Chinese Sex Workers

Sexual transmission has become the primary mode of HIV infection in China (Chinese Ministry of Health UNAIDS and WHO, 2006). Increases in HIV and other STIs, particularly

syphilis (van den Hoek et al., 2001), are associated with expansion of the sex industry in both rural and urban settings (Ding et al., 2005; Pan et al., 2008). Now deeply integrated into China's developing economy, the sex industry is fed by changing sexual norms (Zhang, Details, Liao, Cohen, & Yu, 2008), population migration, and continuing economic need (Liao et al., 2006; Liao & Li, 2009). More effective and sustainable community prevention efforts are needed for this resource limited developing country.

The female condom (FC), a woman-initiated novel barrier method that is as effective as male condoms (MC) for both STI and pregnancy prevention (Kaler, 2004; Liao, Weeks, Wang, Nie, et al., 2011; Mantell et al., 2006; Weeks, Hilario, et al., 2010), is largely underpromoted for prevention worldwide. The different and awkward appearance of the FC and the typical initial difficulty of insertion (Choi, Gregorich, Anderson, Grinstead, & Gomez, 2003; Smit, Beksinska, Vijayakumar, & Mabude, 2006; Vijayakumar, Mabude, Smit, Beksinska, & Lurie, 2006) often lead potential new users to reject FC before trying it or after the first use and induce health care providers and educators to dismiss it before making sufficient effort to get potential users past the initial barriers (Mantell et al., 2011). Additionally, promoting and adopting any new product or behavior designed to reduce STIs requires changing nuanced sexual practices of individuals in various complicated settings in which existing risk and prevention efforts are already entangled.

The China/U.S. Women's Health Project was a partnership between U.S. and Chinese researchers, provincial Centers for Disease Control and Prevention (CDC), and local health care and public health organizations to develop and test a multilevel intervention promoting FC, along with MC, to Chinese women working in sex work establishments. The intervention trials were conducted sequentially in two small rural towns in a single county in Hainan Province, followed by a small, peri-urban county seat in Guangxi Province, and then a mid-sized city in Hainan Province. The four sites varied in size, administrative structure, health and public health resources, sex industry characteristics, and other important social and economic features, but had some similarities. This variation offered the opportunity to assess local conditions that might affect implementation and efficacy of the intervention conducted in sex work establishments to introduce and promote the FC to women working there. Sex work establishments in these towns generally included some boarding houses (single rooms rented out to women sex workers), roadside brothels (some of which had a false business front such as a restaurant or hair salon but no services except sex), massage and beauty parlors (which offered these services as well as sex), hotel-based parlors (only in the urban sites), and nightclubs (only in the mid-sized city). Local partner organizations that delivered the intervention in their town or city included the township hospital in the two rural towns, the municipal CDC in the peri-urban county seat, and a STI/dermatological clinic in the mid-sized city.

Intensive ethnography and three cross-sectional pre-/postintervention surveys were used to document local context, test the efficacy of the intervention conducted in sex work establishments, and explore factors likely to explain variation in intervention implementation feasibility, fidelity, and effectiveness in the different contexts of our four study towns. Our international research team spent 18 months in each study site to complete formative and intervention research, during which two project ethnographers (one from the United States and one from Beijing) spent substantial time living and collecting data in the study communities. During the 4- to 6-month formative period in each site, ethnographers observed and mapped the local sex work establishments and health, economic, and other local resources. They conducted in-depth interviews with establishment owners (bosses), sex workers, and local health providers regarding the sex industry, HIV/STI risks, and existing prevention efforts in the town and among women in the establishments. Six months of intensive intervention delivery immediately followed the formative period and then 6 additional months of intervention maintenance. Ethnographers observed social dynamics inside establishments, the intervention delivered in these settings, and changes at the town level throughout the year. They also interviewed women and establishment bosses about their responses to the intervention and the FC and local project staff about their experiences delivering it. The local health partners in each town tracked their intervention implementation activities using standardized daily/weekly documentation forms. Women's behavioral outcomes and attitude changes were measured by three cross-sectional surveys (baseline, 6 months, 12 months) of the near total sex worker population (75% to 80%) in the two rural towns and the peri-urban county seat and in designated sampled districts of the mid-sized city (Liao, Weeks, Wang, Nie, et al., 2011; Liao, Weeks, Wang, Li, et al., 2011; Nie et al., 2013). All interview, intervention, and other project protocols were reviewed and approved by institutional review boards in the United States and in China.

The local clinical or public health organization that partnered with our study in each town designated staff to implement the project's FC intervention in local sex work establishments. This generally required us to build the capacity of those staff to deliver the intervention in these settings. The skills-building FC-plus-MC intervention that the staff provided was usually conducted in private rooms in the establishment with small groups of women, sometimes in the presence of the boss (if the establishment had one). Staff used a standardized protocol to demonstrate proper FC insertion, troubleshoot common problems with FC use and negotiation, distribute free FC along with MC, and answer other health questions. The protocol required entering each establishment two or more times to provide an initial session plus one or multiple follow-up sessions

for additional support and to reach women not present at earlier sessions. The goal was to enter at least 80% of the sex work establishments in the town (or designated target districts in the mid-sized city) and to deliver intervention to at least 80% of the women working in each establishment during the study period. Frequent migration and turnover of sex workers, as well as needed support to maintain or increase FC and MC use, necessitated repeated visits to the establishments. Time needed for these outreach intervention sessions was substantial and required sustained effort, both to gain entry into the many different establishments in the town and to reach the changing pool of women working in them.

On the basis of our experiences and findings from the mixed-methods data, we compared key infrastructural and social structural characteristics in the four study towns to identify variations and their implications for intervention implementation and outcomes. This systematic structural comparison revealed important contributors at different levels and spheres of interest to the intervention process and to HIV risk that increased or diminished intervention efforts and outcomes in each town. It also revealed important dynamics among these contributing factors. Key actors included women working in the sex establishments and their networks, bosses of those establishments (where present), sex work clients, public/clinic health care providers and health educators, and local police. Key settings included the sex work establishments, the local organization(s) responsible for public and clinical health in the town, the neighborhoods surrounding sex establishments, and the town or city context itself. Key sociocultural, political, and economic factors that shaped HIV risk, prevention, and intervention efforts included sex workers' popular existing practices and beliefs about how to prevent HIV/STIs (including MC use, douching, antibiotics, and others), women's poverty and economic options, policies and their enforcement regarding prostitution and gambling, local stigma or tolerance of sex work, health and prevention resources in the community, and resources in the public health/clinic organization responsible for HIV/STI prevention in each town or city.

In comparing and contrasting our four study towns, we recognized that change processes were happening in these domains simultaneously, that they affected each other as well as our project's intervention implementation and outcomes, and that both negative and positive forces were exerting pressures at the same time that had direct or indirect impact on women's HIV/STI risk and prevention efforts. We used this comparison to construct a system dynamics model, focusing our attention on settings, actors, resources, and the processes linking them in four primary arenas: (a) the sex work establishments, (b) women's social networks, (c) the health organization responsible for implementing HIV/STI interventions, and (d) the town overall.

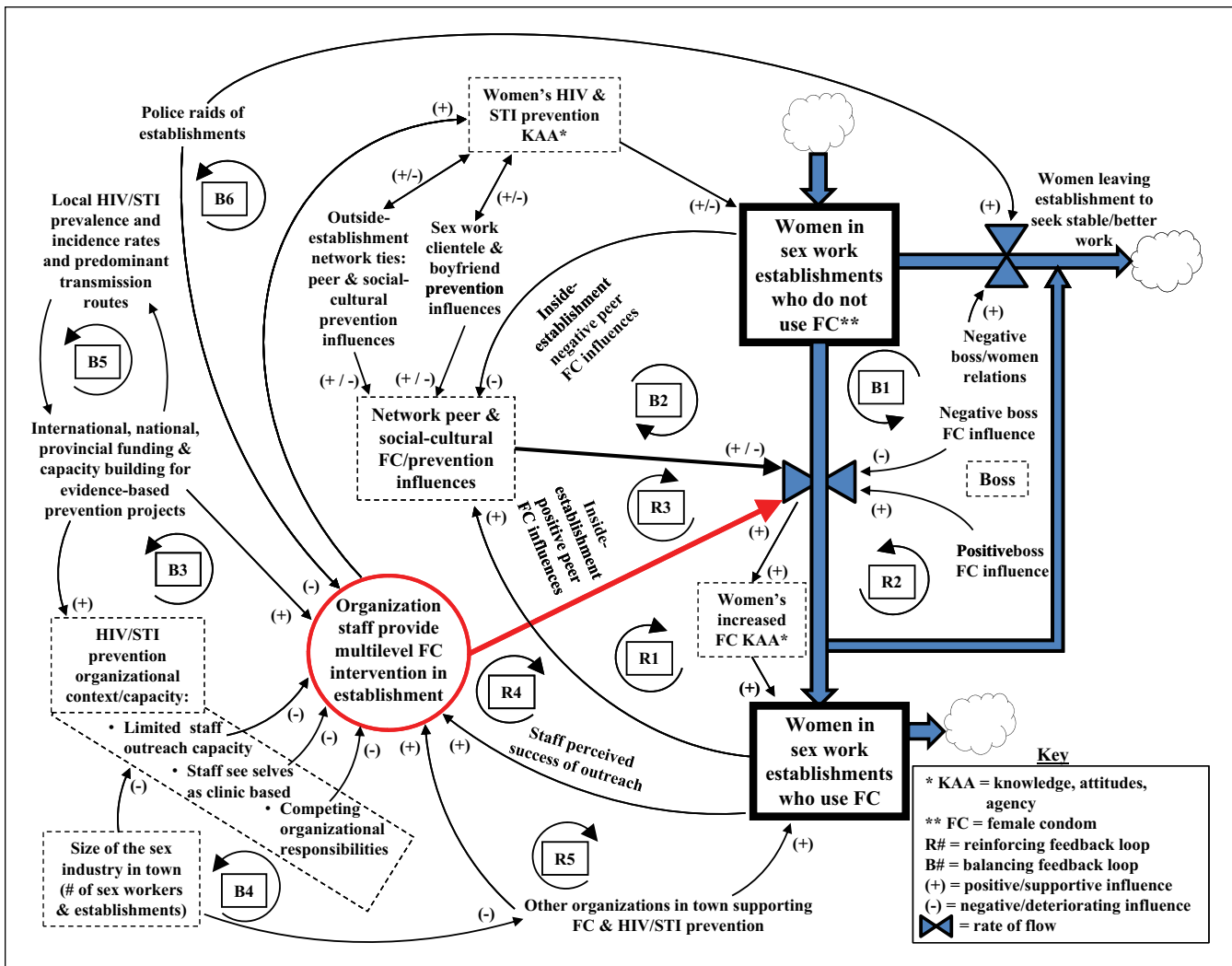


Figure 1. Model of multilevel system dynamics affecting sex work establishment-based female condom (FC) intervention delivery and establishment women's FC use.

Building a System Dynamics Model of Multilevel FC Intervention for HIV/STI Prevention

We began to develop our system dynamics model by identifying key stocks (accumulations of elements in a particular state; Hirsch et al., 2007; Meadows, 2008) of interest to the problem of reducing heterosexually transmitted HIV and other STIs among women sex workers. We also identified the most important flows (directions and rates of change) of these stocks from one state to another to achieve the goal of reducing overall unprotected sex among women working in the sex work establishments. We then identified significant dynamic feedback loops of interest that are likely to affect the rates and direction of flows of one stock to another. These include *balancing feedback loops*, which regulate or maintain the status quo or respond in opposition to a force or

pressure, or those in which one process may trigger “turning off” another. They also include *reinforcing feedback loops*, which mutually regenerate or support a force or pressure in a particular direction.

We have developed a causal map (Foster-Fishman, Nowell, & Yang, 2007; Hirsch et al., 2007; Metcalf, Northridge, & Lamster, 2011) to diagram the key elements that emerged from our four-town structural comparison as most directly related to project processes and outcomes (Figure 1). Because the project goal was to increase the number of women working in sex work establishments who use FC as STI prevention, the primary stocks of interest in this model include *women working in sex work establishments who do not use FC*, from which would derive the targeted intervention achievement, *women in the sex work establishments who use FC*. (All italicized emphases reflect key components or dynamics illustrated in the model.) The rate of

flow of sex work establishment women to become FC users is the most important dynamic in model and the primary focus of the establishment-based outreach intervention protocol delivered by a local health or public health organization. An additional relevant flow in this context is the migration of women into and out of the establishment(s), either before or after being exposed to FC intervention delivered there, and after exposure, either before or after becoming FC users in the establishment. The following describes and unpacks the specific subsystems in the causal loop model and the dynamic processes within each that affected the flow of women sex workers in the establishments to become FC users in those establishments.

Women's Agency and Other Individual-Level Change Factors

FC was absent in all establishments prior to our intervention program, but here, as anywhere, it was introduced into an existing context of women's awareness, preferences, and ability to make prevention efforts. Women came to these establishments with their own knowledge and beliefs about HIV/STI prevention, including beliefs about the efficacy of a wide variety of prevention practices and products (some of which have little or no known efficacy) and attitudes, including preferences, about them. They also learned about prevention options from others over time, including bosses, peers, clients, and project staff. Women were differentially able to choose the prevention practices they preferred to use, if any, based on availability, client demands, boss demands, or other pressures. Thus, women's HIV/STI prevention knowledge, attitudes, and agency (KAA in Figure 1) variably affected their prevention practices, including use of the MC or other products, most commonly, douching and antibiotics. This individual-level context factor is likely to generate or impede women's openness to introduction of a novel prevention device like the FC into their existing repertoire of prevention options. Furthermore, after being introduced to the FC by project staff, those who felt positively about it, increased their efficacy to use it, and could get clients to agree to it (i.e., increased their FC KAA) were more likely to become long-term FC users in the establishment. *Women's increased knowledge about FC after exposure to the intervention, their improved attitudes toward it after successful attempts to use it, and their own skills and agency to negotiate for it and use it when available generate a reinforcing feedback loop (R1 in the model) supporting their continued FC use, particularly with recurrent outreach staff intervention delivery.*

Sex Work Establishments

Women's relationships to sex work establishments varied in the four study sites. In the rural towns, women tended to both live and work in the establishment, spending almost all of

their time there. In the urban settings, women were more likely to live outside the establishments, in some cases being called in as needed, and in others, spending working hours there every day. Almost all women were migrants from distant locations, often entering, leaving, and sometimes returning to the same establishment of their own will in response to seasonal changes, holidays, conflicts with other women or the boss, raids or other disruptions, and availability of clients. Likewise, new women entered the establishment, either at the invitation (or trickery) of the boss or others or because they had heard the establishment was a safe and stable place to earn income. These dynamics occurred regardless of the timing and presence of FC intervention provided in the establishment but directly affected whether women stayed long enough to get exposed to intervention and also to become FC users in that establishment.

Not all types of sex work establishments had a boss (e.g., some of the single room rental boarding houses). However, for those that did, presence of the boss or manager in the establishment was critical. Women's migration out of the establishment was affected by whether their relationship with the boss was supportive or conflictive. In establishments with a boss in which women both worked and lived and the boss provided most aspects of women's life and livelihood, their reliance on the establishment significantly influenced their freedom and willingness to leave. Bosses varied in their control over the women and how they exerted power to influence women's work, nonwork activities, interactions with clients, prevention practices, and access to prevention resources. Boss attitudes about HIV/STI risk, MC, and FC directly affected the environment of risk or prevention in the establishment. Bosses were gatekeepers of the sites, effectively determining whether and how often outreach workers could provide intervention there. They were business people, sometimes wanting to keep women in the establishment healthy and maintain a good reputation to improve business, sometimes supporting client preferences not to use condoms even at the expense of women's health, sometimes forbidding sex work in their establishment, despite clandestine sex services from women who skirted the regulations. *In our system dynamics model, we have indicated a reinforcing feedback loop (R2) generated by boss presence and his/her positive support for delivery of intervention in the establishment and for the FC as a beneficial option to prevent HIV and other STIs. This reinforcing feedback loop increases women's repeated exposure to the intervention and also generates an environment supportive of FC that may lead more women in the establishment to try it. However, negative boss FC attitudes and boss obstruction of intervention delivery in the establishment generates a balancing feedback loop (B1), in which boss resistance increases in the face of repeated outreach efforts, and which reduces women's potential exposure to the FC and their likelihood to use it. In sex work establishments with no boss, neither of these boss-related feedback loops is present.*

Women's Social Networks

In sex work establishments where women both live and work, their network ties with other women in the establishment are often multilayered and strong. Where women are called in only for work or where they only spend working hours, network ties among coworkers in that establishment are sometimes equally complex, but often less so. Types of possible inside-establishment network ties among women include the following: live with, eat with, play *mahjong* with (a traditional Chinese board game often with gambling), have hometown ties, have family ties, provide mutual or unidirectional material/emotional support, provide/receive information on prevention practices, share health or safety information regarding clients, and so on. Generally, the greater the number of different types of network ties to another woman, the greater potential influence that relationship has on both women. Thus, inside-establishment network relationships have great potential to influence women's knowledge of, attitudes about, and use of FC. They may also be the primary source of cultural and health information and influence regarding use of other practices that may or may not be effective to prevent HIV/STIs or unwanted pregnancy. With inside-establishment networks, if one woman is strongly opinionated about prevention in general or about a particular option like FC, she has potential to exert great influence over all women in the establishment.

Most women working in the sex industry also have network ties to women sex workers outside their work establishment in the same town (or in other towns), as well as to clients and "boyfriends" (a term used in widely variable ways, which is beyond the scope of this discussion). Where women did not live in the establishment in which they worked, their network ties often bridged different establishments. The types of possible outside-establishment ties with other sex workers include all the same as inside-establishment ties. Additional significant ties may include sources of information about other establishments/bosses (i.e., potential new work locations) and about potential clients. However, because outside-establishment women's networks tend to be more dispersed and often less complex (i.e., fewer different types of relationships with any given woman), the strength of these network ties may be less than inside-establishment ties. Nevertheless, some such ties may be particularly strong, and because of the broader connections outside the establishment, women have great potential over time to contact other women outside their work place who may have been exposed to FC in a different establishment. Likewise, clients may have been exposed to FC from women in the same or other establishments and, whether exposed or not, may have positive or negative opinions about it.

From the combined influence of inside- and outside-establishment networks and clients is generated the total local peer influence on women sex workers regarding the project intervention, the FC, as well as other known and/or common

prevention methods (or reasons *not* to use prevention) that might "compete" with FC and MC use. This includes women's shared information about clients' responses to FC, MC, and prevention in general. Peer influence has been demonstrated to be directly related to adoption of innovations (Rogers, 1995), including the FC (Mantell et al., 2006; Weeks, Hilario, et al., 2010). It can either complement or contradict the influence of intervention providers who promote FC to the women, whose persuasions may carry less weight than that of peers in the sex industry. *We have indicated a balancing feedback loop (B2) in which network peer influences, including shared beliefs about all forms of prevention as well as possible negative influences from FC nonusing peers inside the establishment, interact with outreach worker delivered intervention to affect the flow of establishment women from being FC nonusers to becoming FC users.* In this balancing feedback loop, negative peer influence generates push-back on staff outreach intervention goals, requiring more outreach or more intervention channels at least to keep discussion of FC going and to make FC available; however, as positive peer influence for FC increases, outreach goals are achieved, resulting in less need for staff intervention. *We have also indicated a reinforcing feedback loop (R3) generated by inside-establishment network ties with women who have become FC users.* (The latter may have resulted from either outreach intervention provided in the establishment or peer influence from someone exposed to FC in this or a different establishment.) Close and continuous proximity of women to their inside-establishment FC-using peers is likely to reinforce those peer influences continually over time in support of and supported by outreach staff efforts. Social network peer influence is one of the more complex processes in this system dynamics model because women are likely to have both positive and negative peer influences in their networks, and the type of network ties with each may determine strength of that influence in one direction or the other. However, women may reject the views of their peers altogether based on their own experience, thereby nullifying the peer influence dynamics of B2 and R3.

Organization and Staff Responsible for HIV/STI Prevention

At the time of our study, the FC was not available in any of the towns in which we conducted our research except through the project, primarily delivered in sex work establishments by staff from the local partner organization responsible for HIV/STI prevention. The amount of women's exposure to intervention delivered with fidelity in their establishment(s) was hypothesized to be associated with their FC use. *Thus, outreach intervention delivered in the establishments is indicated in our system dynamics model as the primary mechanism increasing the flow of sex work establishment women who do not use FC into the stock of FC users in those establishments.*

As mentioned above, in three of our four study sites, the partner organization was a clinical-oriented institution, whereas in the remaining town it was the municipal CDC. In all sites, specific organizational staff assigned to deliver intervention needed to gain entry into all targeted establishments and return repeatedly to deliver the intervention to women working there. As staff proceeded with their work over time, bosses and women presented them with varying support or resistance to receiving the intervention and to trying the FC. Where supported, staff felt encouraged to continue because they perceived their own success in achieving the project goals. *We have indicated a reinforcing feedback loop (R4) reflecting the interaction between women's acceptance of the intervention/FC and outreach staff's continued delivery of the intervention in those establishments through staff's own motivations.* This reinforcing feedback includes women's (and bosses') acceptance of the intervention (including being friendly to outreach staff); it also includes adoption of FC (or MC), which is the most encouraging feedback. The result of this dynamic could be beneficial if it leads to reinforcement or ongoing support for FC in those establishments; however, it could also be problematic in that harder-to-reach women might be neglected if staff are discouraged from persisting in those establishments. It also could be neutral if women who reject the intervention are already good MC users and do not need the FC intervention.

An additional dynamic existed within the organization itself that had direct implications for intervention delivery and potential outcomes. Several organizational contextual and capacity characteristics affected the amount, quality, and fidelity of intervention delivered in establishments. Organizational type was important and the degree to which the primary mission of that organization was like or unlike the public health outreach work of the intervention. This was characteristic of the municipal CDC, but not the clinical organizations. The history and general function of the organization relates to staff capacity to engage in outreach, their self-identity as clinical and therefore expecting to remain based in the clinic, and competing responsibilities in the organization that require their time (and may be given higher priority over the FC outreach intervention). Their capacity is enhanced, however, with access to outside funding and training to improve and support their ability to deliver the intervention. *We have indicated a balancing feedback loop (B3) reflecting the organizational-level dynamics that counter staff's effective delivery of the FC intervention in sex work establishments, which may or may not be effectively overcome with additional resources, capacity-building training, and other outside supports.*

Town-Level Characteristics (Selected)

Because of the need to bound a dynamic system in order to study it (Foster-Fishman et al., 2007; Hirsch et al., 2007;

Meadows, 2008), we have limited our discussion here to focus on town-level forces that affect the sex work establishments and the process of delivering interventions there. In this regard, three primary town-level factors are critical: (a) size and types of the sex industry in the town and the number and types of health related resources in the town for prevention and primary health care; (b) prevalence of HIV/STIs as it relates to opportunities for external sources of funding, resources, and pressures to implement evidence-based prevention interventions to reduce the epidemics; and (c) policies and local enforcement efforts to eliminate sex work.

The first town-level factor relates to the feasibility and capacity of organizational staff to reach all establishments and sex workers with outreach intervention, the time required to do so, and the need for targeted approaches to enter and deliver intervention in each establishment, as these continued to change over time. The number and types of other local health organizations supporting or providing prevention intervention also limit or extend capacity to address the town's health care and prevention needs. This town-level characteristic determines which specific organization is responsible for intervention delivery in the establishments and how many other health services that organization provides to the town (which may affect the B3 feedback loop). The presence of other organizations in town (e.g., clinics, reproductive health organizations) that might also provide FC (which did not occur during our study) could assist primary prevention organizations with the task of reaching these women and establishments. *A reinforcing feedback loop (R5) represents the likelihood that other local health organizations' support for prevention organizations to provide HIV/STI prevention and FC promotion interventions will increase adoption of the prevention method among sex workers. Furthermore, we have indicated a balancing feedback loop (B4) to reflect the challenge of the primary prevention organization, with or without the support of other local health organizations, to reach the full sex worker population in their town, particularly in larger towns and cities.*

The second town-level factor has two components. The first is prevalence and incidence of HIV and other STI cases, indicators of need for prevention resources. These resources are usually in the form of provincial, national, and international funding for programs. *We have indicated a balancing feedback loop (B5) in which HIV/STI prevalence and incidence rates generate pressure or opportunities for external funding, usually in the form of project funds for local community prevention efforts and capacity building to engage in those efforts.* Such resources can be a double-edged sword. On the one hand, they can affect accumulation of experience for providing evidence-based health programs (thereby contributing positively to B3 feedback to increase organizational capacity). Outside institutions often bring novel intervention approaches for the local town to implement. These may come with substantial funding, which local health organizations need, and sometimes also bring staff training and

capacity building. On the other hand, external resources also come with significant pressure to focus attention on the specific program or activity being funded, though it may compete with other externally funded projects and also add to the existing burden of the organization's routine responsibilities. Such pressure may lead to resistance; the more funders push, the more organizations push back or otherwise resist the pressure to seek balance in their capacities and responsibilities. However, as the local organization develops greater capacity to implement the intervention and finds ways to embed it in the routine efforts and mission of the organization, external capacity building and funding may be needed less over time. *This dynamic interaction between the various external sources of funding for specific projects and the organization responsible for implementing all these programs contributes to the balancing feedback loop introduced above (B3), in which organizational capacity-building can improve intervention outcomes, but competing program pressures can undermine those efforts.*

A third town-level factor affecting intervention delivery, its efficacy and impact on HIV/STI prevention, and FC adoption are policies and campaigns to eradicate prostitution, gambling, and other public security concerns, usually directives generated by higher levels of government. When enforced locally, this generally takes the form of police raids of sex work establishments. The four study towns varied dramatically in the degree to which this occurred; it was exceptionally rare in the rural towns but routine and cyclical in the mid-sized city. Also, it varied in different types of establishments, making some more vulnerable to raids than others in the same town. Police raids of establishments have the immediate effect of shutting down business (usually temporarily), sometimes resulting in women's out-migration. It also disrupts women's network ties (and potential peer influences) and curtails provision of prevention intervention in the establishment. *We indicate a balancing feedback loop (B6) representing the interaction between police raids and prevention intervention delivery in the establishments.*

Potential Applications and Opportunities to Test the Model

The system dynamics model presented here is the initial attempt at model development based primarily on ethnographic findings from our four town establishment-focused multilevel intervention trial. As stated above, the trial was not originally designed to test system dynamics or intervention outcomes using this model. Though our community-based intervention trial focused on the elements of the model and their (linear) relationships to FC intervention delivery and FC use, without the benefit of the system dynamics framework and model presented here, we could not systematically test various interactive system components and feedback loops. That would require further efforts, for example, to change elements of the system or assess variations and

observe effects on other parts of the system and the rates of change affected by balancing and reinforcing feedback loops over time.

Reconceptualizing the factors and dynamics that shaped and affected implementation and outcomes of our multilevel intervention using a system dynamics framework has several advantages (Foster-Fishman et al., 2007). It allows better recognition of how and why change occurred in the way and at the rate it did in women's social networks, as well as within and across different establishments and in the community that were related to introduction of the novel prevention device (FC). It further facilitates identification of specific roadblocks to the partnering organization staff's delivery of intervention, as well as possible mechanisms to reduce those barriers or adjust the intervention, though not all factors in this model are easily modifiable. Furthermore, this framework promotes multilevel model testing that integrates the simultaneous balancing and reinforcing, positive and negative forces of change, while also testing multilevel factors that interact to generate project outcomes (Hawe et al., 2009; Hirsch et al., 2007; Latkin et al., 2010). This conceptualization also allowed recognition of delays (time lags) as a significant factor in the intervention process and outcomes.

The significance of attending to the dynamic balancing and reinforcing feedback loops represented in our model and recognizing their impact on our intervention was not apparent to us at the start of our study. However, the effects of these dynamics became increasingly evident as we moved from the simpler to the more complex study sites. When we began the intervention test in the two rural towns, we focused primarily on the content of the outreach intervention to provide women the knowledge and skills they needed to adopt FC as a prevention option in the local sex work establishments, which in these towns were predominantly structured to house women as well as provide a workplace. We directed our focus on the establishment-delivered intervention design, based on a conceptual model that included individual-level knowledge and skills building as well as efforts to address within-establishment network influences (women-women and women-boss relations), although we were not aware of the reinforcing loops R1, R2, R3, and R4 as potential leverage points. However, we observed that project staff from the township hospital in one of these two very similar rural towns were better able to implement the intervention in the establishments than staff in the other town and that this was related to differences in their outreach experience with prior national and international projects (B3). We also conducted some community-level intervention in both rural towns to introduce FC to other local health providers to seek their support for women's FC adoption, without realizing that this force could potentially support the local partner organization (the township hospitals) to increase their outreach capacity and improve staff-perceived outreach success (R4, R5), and we did not involve those organizations in the intervention process.

When we moved the intervention to the small city, we discovered that the outreach intervention worked extremely well, even with the increased size of the local sex industry, increased complexity in women's cross-establishment mobility and client variation, and broader social network influences, given that most women lived outside their workplaces and many worked in more than one place. This can be explained largely by the amplifying effect of reinforcing loops R2, R3, and R4, which were fueled by the frequent and effective outreach efforts of the partner organization (the municipal CDC), built on strong trusting relationships between the CDC staff and the women and bosses in the local sex industry. Frequent staff outreach efforts resulted from their outstanding outreach capacity, minimal perception of themselves as clinic based, and fewer competing organizational responsibilities (factors we now attribute to B3). These feedback loops not only significantly increased the study's short-term and mid-term efficacy in this site but also sustained the intervention's long-term effects. Even after our project funds had stopped for more than a year, the municipal CDC continued implementing the adapted version of our study's FC intervention with external support for FC supplies.

When we moved to our final study site, the mid-sized city, we encountered the largest and most complex sex industry in all our sites (B4), with most women living outside their work place and moving frequently, regular police raids especially in some establishments (B6), and the most complex local health care and public health infrastructure of all the sites. We also discovered that strong resistance to outreach by the local staff from the partner STI/dermatological clinic and their lack of prior experience and basic capacity to conduct outreach became a roadblock for intervention delivery (B3). This was the clearest evidence to date of the importance of expanding our intervention model to include the dynamic pressures within the partner organization in order to understand implementation processes and outcomes. The consequences of staff's minimal outreach intervention effort resulted in an extremely low FC adoption rate in the first few months of intervention delivery, without the benefit of the reinforcing feedback loops (R1, R2, R3, R4). After we began to understand organizational contextual factors, with provincial CDC support, we put more emphasis on addressing the leaders' and staff's outreach awareness and capacity and their definition and perception of intervention success. As their outreach capacity and comfort level improved, we began to observe similar outcome effects and patterns as in other sites, though to a lesser degree. This also suggested that it is insufficient to rely on behavioral outcome measures (i.e., FC adoption rate) and outreach intervention exposure alone to assess multilevel community-based intervention outcomes. It is necessary to understand the mechanisms of change in local contexts in order to maximize intervention effectiveness and sustainability.

Focusing on system dynamics has some challenges and limitations. Some elements of the system and the dynamic

processes (feedback loops), as well as the time element, may be difficult to operationalize and measure. However, in system dynamics modeling, variables are not automatically excluded from consideration if recorded measurements on them are lacking. When subject matter experts agree that a factor may be important, it is included in the model, and then the best effort is made to specify and measure it (Hirsch et al., 2010).

Also, any systems model must exclude some factors (Hirsch et al., 2007). In particular, it is difficult to incorporate individual-level idiosyncrasies into the model. Yet these may have great significance on both the processes and effects in the whole system and within specific domains. Some interpersonal relations in our model have been folded into a broader set of factors, such as women's relationships with boyfriends, husbands, and clients. These may need to be considered separately from other "peer influences" in order to disentangle the distinct dynamics sexual relationships and their contexts have on the intervention and on FC use. Likewise, some known sociocultural conditions may play a larger role within multiple contexts than is evident in our model. For example, the existence and popularity of alternative competing prevention options that may "replace" FC, including some that are ineffective for HIV/STI prevention like douching and routine antibiotic use, may generate a different set of feedback loops not adequately represented here. Furthermore, to focus and make our model comprehensible, we excluded many external (e.g., town-level, county/provincial/national, etc.) factors and dynamics that might also be highly relevant to the present discussion. However, by doing so, we are able to pay closer attention to those domains and forces most immediately relevant to our establishment-based intervention delivery and women sex workers' use of the FC.

As with all other models, this model does not and will not perfectly fit the real world (Meadows, 2008; Sterman, 2002). However, identifying key elements and the relationships that link them and using this to identify "leverage points" (Foster-Fishman et al., 2007; Hirsch et al., 2007; Meadows, 2008) for systems change might greatly improve intervention outcomes and sustainability of impact. We believe that more work is necessary to refine the model. This could include computer simulation of various scenarios and tests of the model in various communities for its functionality, validity, and sensitivity. With this model as a conceptual tool, it is now possible to develop and test hypotheses about elements of the model and their dynamic relationships, refocusing on and giving greater attention to systems processes, for both explanatory and predictive purposes. Developing effective measures of some elements, change processes, and time factors may present challenges. Measurement and hypothesis testing of this system dynamics model is likely to require an integrated mixed-methods approach that synthesizes qualitatively and quantitatively data from multiple sources and from repeated observations over time. Furthermore, since the four study sites of our project mirror similar contexts of

many other Chinese towns and cities, this system dynamics model has significant application value for similar work elsewhere in China, or for introducing other innovative prevention strategies, such as HIV-preventive microbicides, into Chinese sex work establishments. It also has potential for application in other areas of the developing and developed world where sex work is based in establishments.

Conclusion

Deeper examination of system dynamics processes to understand multilevel community intervention outcomes reveals the real-world challenge of creating social, cultural, and behavioral change. Because of the complexity of systems structures, changing them usually takes a long time. The conventional outcome evaluation time frame for individual-level interventions is usually insufficient to observe systems change. However, once the intervention has changed the system to the desired structure and function, it tends to be self-sustaining, a significant and desirable implication in resource-poor countries like China.

Furthermore, dominant research designs to test novel interventions, most commonly using randomized controlled trials (RCTs), fail to meet the methodological requirements for examining and testing complex multilevel processes and interventions designed to change community systems (Bonell, Hargreaves, Strange, Pronyk, & Porter, 2006; Manhart & Holmes, 2005; Sanson-Fisher, Bonevski, Green, & D'Este, 2007). Methodologies using alternative research designs, such as rigorous qualitative, observational, and network studies (Fortmann et al., 1995; Madon, Hofman, Kupfer, & Glass, 2007; Stave, 2002; West et al., 2008) and comparative case studies (Carey, 2010; Matheson, Dew, & Cumming, 2009), can address this challenge. These alternative methods also generate more comprehensive empirical data and theoretical constructs allowing the development and testing of dynamic models of interactive and complex systems, which generally take into account a broader contextual framework than typical RCT studies can. No human health phenomena occur within a simple and easily defined system. Though RCTs may contribute to good understanding of the independent role of each factor in a causal framework, this is not all that matters for health outcomes. The dynamics and interactions of factors and the process also determine results. Only by understanding the mechanisms of the complex system (i.e., what is inside the "black box") can scientists, health providers, and policy makers adjust and then improve interventions for better population-level health outcomes.

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