1-18-2013

The Social and the Sexual: Networks in Contemporary Demographic Research

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Abstract

The analysis of networks has become an important theme in contemporary demographic research in both developed and developing countries, including investigations of the determinants of fertility behaviors, the interaction between social network and social structures and population policies, the role of intergenerational networks in aging societies, and the relevance for sexual networks for the spread of HIV AIDS. This paper reviews the current research on networks across several domains in demographic research, and it discusses some of the specific challenges of network-based approaches with respect to data collection, analytic approaches and methodologies, interpretation of results, and micro-to-macro aggregation by drawing on research conducted as part of the Kenyan Diffusion and Ideational Change Project (KDICP), the Malawi Longitudinal Study of Families and Health (MLSFH) and the Likoma Network Study (LNS).

Keywords

Fertility, HIV/AIDS, Malawi, Sexual networks, Social networks

Disciplines

Demography, Population, and Ecology | Social and Behavioral Sciences | Sociology

Comments

Kohler, Hans-Peter, Stéphane Helleringer, Jere R. Behrman and Susan C. Watkins. 2013. "The Social and the Sexual: Networks in Contemporary Demographic Research." PSC Working Paper Series, PSC 13-01.

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The analysis of networks has become an important theme in contemporary demographic research in both developed and developing countries, including investigations of the determinants of fertility behaviors, the interaction between social network and social structures and population policies, the role of intergenerational networks in aging societies, and the relevance for sexual networks for the spread of HIV AIDS. This paper reviews the current research on networks across several domains in demographic research, and it discusses some of the specific challenges of network-based approaches with respect to data collection, analytic approaches and methodologies, interpretation of results, and micro-to-macro aggregation by drawing on research conducted as part of the Kenyan Diffusion and Ideational Change Project (KDICP), the Malawi Longitudinal Study of Families and Health (MLSFH) and the Likoma Network Study (LNS).

1 Introduction

Theories of social interactions in demography rest on the insight that individuals do not make decisions about demographic and other social behaviors in isolation, but rather with others. Rather than being constituted merely by collections of individuals, populations consist of interconnected networks of persons who share information, resources and often a common understanding of norms. Understanding this interconnectedness is essential for understanding demographic behaviors and the dynamics of demographic processes. While the basic insight about the relevance of social interactions is old, dating back at least to the 19th century with the work of the sociologist Simmel (1922), in recent decades researchers have made substantial progress in specifying, measuring, modeling and understanding the importance of network-based interactions on human behaviors on the micro-level, and on societal, economic and cultural dynamics on the macro-level (e.g. Burt 1982, Fischer 1982, Laumann et al 1983, Granovetter 1973, Marsden 1993, Valente 1995, Montgomery and Casterline 1996) . A recent book *Connected: The Surprising Power of Our Social Networks and How They Shape our Lives* (Christakis and Fowler 2009) claims that "*how we feel, whom we marry, whether we fall ill, and how much money we make and whether we vote—everything hinges on what others around us are doing, thinking and feeling*." While this specific claim is rather bold and controversial (Kolata 2011), there is indeed growing evidence that a broad range of fertility, health and related behaviors are associated with, and sometimes even causally affected by, a person's social networks. For example, there is an extensive literature on the importance of social interactions and the diffusion of innovation for the decline in fertility during the demographic transition or in contemporary low- fertility contexts (Behrman et al. 2002; Bernardi 2003; Bongaarts and Watkins 1996; Hensvik and Nilsson 2010; Kohler 1997, 2001; Kohler et al. 2007; Lyngstad and Prskawetz 2010), and recent studies have linked a variety of health outcomes to social network structures, including for instance smoking, alcohol and substance use, obesity, HIV risks, mental health, risk perceptions, and subjective well-being (e.g. Andrews et al. 2002; Bearman et al. 2004; Christakis and Fowler 2007; Fiori et al. 2006; Fowler and Christakis 2008; Helleringer and Kohler 2007; Kaplan et al. 2001; Smith and Christakis 2008).

Several reviews of the network literature have described the origins of network theories and analyses (e.g., Wellman 1988). Network studies were given an early applied focus by European anthropologists studying rapid social change associated with modernization in sub-Saharan Africa, who wrote of the network connections of urban migrants with each other and with the rural communities from which they came (Mitchell 1969) and by anthropologists studying class relationships in Britain (Bott 1971). An interest in social networks then developed among U.S. sociologists. In some cases, the analyses focused more on theories and methods of network analysis (Burt 1982; Marsden 1990; Valente 2005) while other focused more on substantive issues: for example, Fischer (1982) analyzed personal networks to investigate the social and psychological consequences of urban life, and Granovetter (1973) emphasized the importance of *weak ties* that transmit unique information across otherwise largely disconnected segments of social networks, thereby facilitating the diffusion of new information. *Strong ties* and dense networks, on the other hand, are more likely to enforce norms and conventions that represent a proper way to behave. In a similar vein, Burt (1992) pointed to the strategic informational advantage that may be enjoyed by individuals who bridge *structural holes*, that is, those with ties into multiple networks that are largely separated from one another. Social interaction processes and their effects on social dynamics have also been investigated extensively in the context of the diffusion of innovations (e.g., Rogers 2003), social change and collective action (Kim and Bearman 1997; Klandermans 1992), and search or matching processes in the labor market or similar markets (Granovetter 2005, 1973).

In demography, an important stimulus to incorporating social networks in analyses was the attempt to explain patterns of fertility declines in historical Western Europe and the developing world. Although it was expected that fertility declines could be understood as individual responses to structural changes associated with modernization (e.g. urbanization, the transformation of the labor force from agricultural to industrial, declines in infant and child mortality), the associations between measures of these changes and fertility declines were typically modest (Cleland and Wilson 1987; Coale 1986). This led to postulating the importance of interpersonal diffusion (Knodel and van de Walle 1979) and the use of social network theory to structure analyses of diffusion (Casterline 2001; Montgomery and Casterline 1996; Munshi and Myaux 2006; Watkins 1991). Applications in demography have also included the perception of mortality change (Montgomery 2000, Sandberg et al, 2012), the onset of sexual behavior among teenagers (e.g., Rodgers and Rowe 1993), and international migration (Massey et al. 1994; Munshi 2003). Conceptually, the analyses of fertility change have focused on two mechanisms through which fertility and contraceptive behaviors might be influenced by social interactions: social learning and social influence (Montgomery and Casterline 1996). The former postulates that decisions about fertility and contraceptive adoption are subject to substantial uncertainty, for example, about the medical side effects and/or the costs and benefits of modern methods of family planning. Learning about other women's experiences through networks may reduce this uncertainty, thus increasing the probability that a risk-averse woman will adopt modern contraception herself. The second aspect, social influence, emphasizes normative influences on behavior rather than processes of learning about unknown characteristics. Social influence therefore implies that the fertility-related opinions and behavior of an individual's network partners influence and alter her preferences regarding modern contraception and/or number of children.

Despite evidence collected by demographers interested in understanding incipient fertility declines in the developing world, and advocates of interestedthe adoption of modern contraception—evidence that villagers talked to each other about family planning and family size—demographers paid little attention to the role of social networks prior to the 1990s. In part this was due to the absence of data on networks; that absence, however, was due to a dominant model of social behavior that privileged individual and family characteristics over social interactions. Only in the 1990s were new data collected in developing countries that permitted detailed descriptions of social networks and rigorous analyses of social network effects, for example in Ghana (Montgomery et al. 2001), in Thailand (Entwisle et al 2007), in Kenya (www.kenya.pop.upenn.edu) and in Malawi (www.malawi.pop.upenn.edu).

An important limitation of much of the literature on social networks and healthhas been the use of *egocentric* (or local) network data in the majority of studies on this topic. Egocentric data provide information about the social ties of a survey respondent, but contain no information about the larger network in which the respondent is embedded. Thus, egocentric network studies provide only a very restricted view of a person's social capital and do not allow analyses of how global/local network structures and a person's structural position within a larger community-level social network affect important health outcomes (e.g., Smith and Christakis 2008). Another approach to collecting network data consists of conducting a census of individuals and their relations in a small, well-defined population. This approach, known as sociocentric data collection, has frequently been used in the sociology of organizations, but it is more complicated to employ in the larger populations demographers typically study. Recognizing the limitations of egocentric network data, a small but growing number of researchers have begun to collect *sociocentric network data* (a.k.a. sociometric, complete, or global networks), in which all or nearly all members of a community or group and their linkages to each other are represented as part of *saturation samples*. While egocentric data include only the direct links from the focal individuals (the "*egos*") to other persons, sociocentric networks include both direct and indirect ties and allow mapping community-level network of social relationships. Sociocentric data are less affected by measurement error because all social relationships, and the interactions among network partners, are potentially reported by each of the two members of the relationship. In addition, utilizing the recent advances in network theory (Carrington et al. 2005; Morris 2004), sociocentric network studies—especially when they are longitudinal—can identify the complex patterns of interrelations among persons and their health. Path-breaking results, for example, came from analyses of the Framingham Heart Study, for instance in studies showing the spread of obesity through social networks (Christakis and Fowler, 2007), or the sociocentric Adolescent Health Study (AddHealth), including findings that obese adolescents are often socially isolated in networks of high school students (Strauss and Pollack 2003), and Bearman et al.'s (2004) finding that over an 18-month period in a Midwestern high school, connected 52% of all romantically involved students so that they were embedded in one very large spanning tree. Recent work on the Framingham study highlighted the role of social networks in the growing obesity epidemic, or in changes in smoking behaviors. Finally, we have recently shown that sexual networks in sub-Saharan Africa can be much more extensive than was previously thought. For example, half of all sexually active respondents on Likoma Island in Malawi were linked together in a *giant network component*, and more than one quarter of these were connected by multiple *independent* chains of sexual relations. Such structural features of sexual networks have been associated with epidemic spread of STIs in high-risk groups (Moody et al. 2003; Newman 2002; Potterat et al. 2002; Rothenberg et al. 1998), but prior to our study

(Helleringer and Kohler 2007), had never been documented among general population in developing countries.

2 General Overview of Survey Data and Contexts

Within demography, where an important focus has been the empirical measurement and identification of social interaction effects on fertility and health outcomes, relying primarily on sociocentric network data and concerned mostly with the estimation of peer effects on individual behaviors. In a few cases, researchers—including the authors of this paper—have collected longitudinal data that permit careful description and rigorous analyses of the causal impacts of networks. Our work for well over a decade in investigating the roles of interactions in social—and more recently also sexual—networks for important demographic behaviors has been based on data collected in Kenya and Malawi. In our review of this work, we begin with analyses using data from the Kenyan Diffusion and Ideational Change Project (KDICP) and the Malawi Longitudinal Study of Families and Health (MLSFH; formerly Malawi Diffusion and Ideational Change Project, MDICP), which featured egocentric network data. In the second part of this review we turn to sociocentric network data collected on Likoma Island in Lake Malawi, where our analyses have tried of infer the population-level size and structure of sexual networks that are related to the spread of HIV.

The KDICP and the MDICP conducted panel surveys of households and qualitative data. In both cases the initial primary motive for collecting these data was to analyze the role of social networks in the diffusion of innovations to increase the use of modern family planning methods and to reduce fertility, provoked by the limited explanatory power of individual characteristics to explain the European fertility decline (see the introduction). Subsequently the focus of the projects—and therefore of the data collection—shifted increasingly towards HIV/AIDS because of the rapid spread of the epidemic in the populations being studied. The surveys were conducted in in rural areas between 1994–2000 for Kenya and 1998–2010 for Malawi); to compensate for sample attrition in Malawi, a sample of adolescents was added in 2004. Longitudinal qualitative data on responses to the epidemic were collected between 1999 and 2010 in Malawi, and in both countries there were qualitative studies on other topics .

The KDICP and MLSFH data are, to our knowledge, unique in including detailed accounts on women's and men's social interactions about family planning or the HIV/AIDS epidemic.[1] In particular, the data include information on egocentric networks contain the respondent and those with whom the respondent had chatted about family planning or HIV/AIDS, with detailed information on up to four network partners. The term "*chat*" was used in survey questions to indicate informal conversations rather than lectures at clinics. Respondents were first asked about the number of people they had chatted with about family planning or AIDS, followed by a series of questions about these network partners (covering a maximum of four network partners if more than four were identified). [2] The data on the network partners include relationship (e.g., co-wife, sister-in-law, uncle,); the degree of closeness (confidant, friend, acquaintance); the network partner's age, sex, and wealth; and respondent's perception of views and behaviors of the network partner on family planning or their risk of becoming infected with HIV. .

In Kenya, the first wave of the longitudinal household survey (KDICP 1) was conducted in December 1994 and January 1995 in South Nyanza District, near the shores of Lake Victoria. The second wave (KDICP 2) re-interviewed these women and men two years later, and a third wave was conducted in January and February 2000 (KDICP 3). Only the second and third waves of the survey addressed AIDS. In total, 545 ever-married women (408 husbands) participated in both of these last two rounds of the data collection. In Malawi in 1998, the project interviewed 1,541 women and 1,065 men who were husbands of the women respondents on topics related to AIDS and family planning (MLSFH 1) in the

Rumphi (North), Mchinji (Center), and Balaka (South) regions. Follow-up surveys were conducted in 2001 (MLSFH 2), 2004 (MLSFH 3),2006 (MLSFH 4), 2008 (MLSFH 5) and 2010 (MLSFH 6). Details of data collection and analyses of attrition and data quality are available at http://www.malawi.pop.upenn.edu and in a special issue of Demographic Research (Watkins et al. 2003).

The second part of our analyses in thisi paper focuses on the Likoma Network Study (LNS), an innovative sociocentric *sexual network survey* in Likoma, a small island in Lake Malawi with high HIV prevalence (Figure 1).[3] The key feature of these data is two rounds of data on sociocentric—rather than ego-centric as in most other studies—sexual networks covering the young adult population in seven villages of Likoma. The data were collected in 2005/6 and 2007, and included detailed information on the socioeconomic and demographic context of individuals, as well as information about their subjective health, AIDS related behaviors, attitudes and risk-perceptions and sexual network partners. Studies using a design similar to that of the LNS have been conducted in different contexts (e.g, Bearman et al. 2004; Klovdahl et al. 1994), but there were none for African populations with generalized HIV epidemics.

In order to describe fully the sociocentric sexual networks on Likoma, the data collection occurred in three stages. First, we conducted a census of every individual on Likoma island to obtain a roster of potential partners. Second, we conducted a sexual network survey with *all* individuals aged 18–35 (LNS 1) or 18–50 (LNS 2) in the study villages (Figure 1), asking respondents for information about their romantic and sexual partners. Finally, this saturated sampling strategy permitted us to construct the population-level sexual network by matching the reported sexual partners with the census roster, and then linking the data of all young adults residing in the sample villages. The context and methodology of this survey are summarized below, and additional details are provided in Helleringer et al. (2009a) and Helleringer et al. (2013).

3 Social Networks and the Diffusion of Family Planning

This section summarizes three papers on different dimensions of social networks in the adoption of modern methods of family planning in the high-fertility poor developing context of rural Kenya.

3.1 Empirical Assessments of Social Networks, Fertility and Family Planning Programs

Important long-standing concerns in demography have been the evaluation of the role of family planning programs in facilitating the decline of fertility during the demographic transition, and the investigation to which extent diffusion processes have contributed to individual-level and population-level fertility change (e.g., Kohler 2012). This section emphasizes that these two issues cannot be addressed independently, and that there are important implications of social interaction processes for measuring and interpreting family planning program effects. To provide intuition for some dimensions of our analysis in this section as well as below, we first present a simple model to illustrate some of the advantages that our data have for such analysis. The availability of unusual longitudinal data on social networks and the use of statistical methods that control for unobserved factors provided a unique opportunity to extend the individualistic rational-actor models to incorporate social interaction and to estimate the causal effects of social networks on attitudes and behaviors under certain assumptions about the nature of the unobserved effects. In particular we use an empirical specification of the relation determining contraceptive behaviors in which there is explicit recognition that, in addition to observed right-side variables (including social networks prior to time *t*), there are unobserved fixed factors that might affect both contraceptive use directly and through social networks. For example, preferences for family orientation or for traditional types of social relations might affect both. A first-order linear approximation to the model for the determinants of contraceptive behavior is $Y_{it} = a \cdot N_{it-} + b \cdot X_{it-} + f_i + e_{it}$, where Y_{it} is the observed contraceptive behavior of individual i at time t; N_{it-} is the social network for individual i prior to time t (we use the subscript "$t-$" to emphasize that the variable N refers to the time prior to t; we use this notation also for other predetermined variables); X_{it-} is a vector of other state variables for individual i determined prior to time t (e.g., age, marital status, completed schooling of adults, wealth indicators); f_i represents unobserved fixed factors that are assumed to affect directly contraceptive behaviors by individual i (e.g., the persistent part of preferences, unobserved current community characteristics, expectations regarding future prices, and interfamilial and community resources on which the individual can draw) and also affect social networks; and e_{it} is an i.i.d. disturbance term that affects the contraceptive behavior of individual i at time t due to, for example, new information on the probability of conceiving children from using traditional contraceptive methods or about the advantages and disadvantages of children in a high HIV/AIDS prevalence context, or price shocks that are deviations from the long-run secular price trends.[4] This modeling approach to social interaction is consistent with Montgomery and Casterline (1996) social multiplier model of diffusion in which, if b is the direct impact of some change in X_{it} on an individual's behavior Y_{it} and N_{it-} are measured in the same terms (e.g., Y_{it} is the ith individual's contraceptive behavior and N_{it-} is the average contraceptive behavior by social network partners), the social multiplier that captures the long-run effect through the network is $1/(1-a)$. Therefore, to estimate this social multiplier, as well as the direct determinants of contraceptive behaviors of an individual, it is important to obtain unbiased estimates of the coefficients a and b.

While the above linear model is conceptually simple, this is not necessarily the case for the estimation of the relevant parameters of this model. In particular, if OLS estimates are made of the above linear equation, inconsistent (biased) estimates are likely to result because the unobserved fixed effects are correlated with the characteristics of social network partners if they indeed affect the choice of network partners, so the OLS estimated value of a is biased because the social network variable is representing in part the unobserved fixed effects in addition to the effects of social network per se. By virtue of having longitudinal data, however, we are able to control for the individual fixed effects to compare the fixed effects estimates with the OLS estimates to learn how much difference control for unobserved fixed effects makes in inferences about the magnitudes of network effects.[5]

Before returning to the challenges and potential solutions for estimating the importance of social interactions from empirical data, we use the above framework to illustrate how social interactions can change the interpretation of how family planning programs affect fertility behaviors, and how assessments of the relevance of family planning programs can depend on whether the analyses account or do not account for the presence of social learning and/or social influence through networks. Specifically, we continue with the assumptions of a linear model and assume that the probability that a woman adopts modern family planning ($y = 1$) is given by $P(y = 1|z, y_c) = a\cdot(-.5 + y_c) + b*z + d$, where the term $a\cdot(-.5 + y_c)$ represents the influence of social interaction on a woman's probability of using family planning. The parameter a reflects the 'strength' or relevance of social interaction and determines the extent to which the adoption probability is affected by the contraceptive behavior in the reference group (y_c), which for concreteness in what follows we assume is the village in which a woman lives. If the contraceptive prevalence in the village (y_c) is above 0.5, then social interaction increases the probability of using family planning as compared to the situation when no social interaction is present, and otherwise it decreases the probability. The coefficient b is the direct effect of program efforts (z), and larger program efforts increase the probability of using contraception when $b > 0$.[6] The solid line in Figure 2a then plots the curve implied by the above linear social interaction model: the vertical axis gives an individual's probability of using contraception as related to the average contraceptive use for the individual's village (y_c, on the horizontal axis) given the program effort z (e.g., proportion of other villagers who *heard a family planning message on the radio*). The slope of the solid line indicates how the probability of individual use changes when there is a discrepancy between the probability of an individual's use and the average contraceptive use of other women in her village. The linear model in Figure 2a exhibits only one equilibrium, the point at which each individual's behavior mirrors the village average—where the solid line intersects the 45° ray from the origin in Figure 2a. This equilibrium therefore satisfies $P(y = 1|z, y_e) = y_e$, where y_e is the equilibrium level of contraceptive use. To the left of it the individual probability of use is above the village average use; therefore the average village use increases because the individual is in the reference group for others in the village, which causes movement to the right towards the equilibrium (and vice versa to the right of the equilibrium).

The above linear framework is useful for illustrating the effects of an increase in family planning program effort in the presence of social interactions about contraceptive use. The increased family planning effort can for instance be due to a new media campaign. This increased program effort then results in an increase in the probability of using family planning, and this upward shift of the propensity to use family planning before accounting for any additional social interaction effects is indicated in Figure 2a as the *direct program effect*. This direct program effect is not modulated by social interactions. If, however, the individual adjusts to her reference group through social learning and/or social influence, we get a social multiplier (Montgomery and Casterline 1996). The social multiplier leads to a new and higher equilibrium level of contraceptive use, i.e., where the dashed line intersects the 45° ray. The total increase in the probability of contraceptive use is thus the *total program effect*, consisting of a direct program effect plus its multiplication by the social interaction term.

In addition to the linear social interaction model in Figure 2a, it is useful to also consider a nonlinear social interaction model that is frequently used in theoretical models of social interactions (Durlauf 2001; Kohler 2000; Kohler et al. 2000; Manski 1993) and for empirical estimates (Arends-Kuenning 2001; Godley 1999; Kohler et al. 2001). In this model we assume that the disutility from deviating from the average behavior of woman's reference group is related linearly to the difference between an individual's decision to use or not to use and the average reference group behavior y_c. More specifically, we assume that the social utility term takes the form of $a\cdot(-.5 + y_c)$, where .5 is the critical level above which the prevalence of contraceptive use in a woman's reference group has a positive influence on the adoption of family planning, and a is the 'strength' or relevance of this social interaction effect. The standard derivation leads to the probability that a woman uses a modern method of family planning given by a logistic model as $P(y = 1|z, y_c) = F(a * (-.5 + y_c) + b * z + d)$, where d is a constant including the effect of the individual characteristics and F is the cumulative logistic distribution. The total effect of family planning programs in the presence of social interactions can be characterized in the above nonlinear model, as in the linear case, by equilibria in which an individual's choice probability mirrors the reference group average (Figure 2b). That is, an equilibrium is a level of contraceptive use that satisfies $P(y = 1|z, y_e) = y_e$, or equivalently, an equilibrium is a fixed point at which $y_e = F(a * (-.5 + y_e) + b * z + d)$. These equilibria are thus at intersections of the "s-shaped" curve $F(.)$ with the diagonal. The solid line in Figure 2b displays a case in which only one such equilibrium exists. The solid line in Figure 2c, on the contrary, shows a case with three intersections. The equilibria at low and high levels of contraceptive use are stable for reasons parallel to those discussed with regard to Figure 2. The same reasoning, however, indicates that the center equilibrium always is unstable. A population converges to one of the two stable equilibria depending on whether it is to the left or right of the unstable equilibrium.

The comparison of the linear and nonlinear specification in Kohler et al. (2000), including both the theoretical implications of a linear versus nonlinear specification as well as the differences of these models in their empirical estimation using KDICP data, yield the following major results:

First, as noted, we distinguish between the direct effects of a family planning program on an individual's probability of using family planning and the indirect effects due to social interaction. Our empirical estimates show that the nonlinear model of the relations among program effects, social interaction and of modern family planning leads to some fairly large differences in the estimates of program effects from those obtained with the linear model—e.g., with estimated direct program effects on the ever-use of family planning from 20% lower to 27% higher for the linear than the nonlinear model. We then show empirically that in our data as much as 43% of total program effects are due to social interactions.[7] This social multiplier effect is due to a feedback loop that occurs because social interactions render the family planning decisions of community members interdependent. Because of this social multiplier, attributing all of the total change in contraceptive behavior to the direct impact of changes in program effort would be a substantial overestimate of the true direct program effect.

Second, if the model is nonlinear (Figure 2b-c), there may be both a low-level Malthusian equilibrium in which contraceptive use remains relatively low despite ongoing program efforts as well as an equilibrium in which contraceptive use is high.[8] If a population is at a low-contraceptive-use and high-fertility equilibrium—a situation that may characterize much of sub-Saharan Africa, including places with family planning programs—small program changes have relatively small effects. However, large increases in program efforts—even if transitory—may cause a shift to a high-contraceptive-use and low-fertility equilibrium. In a linear model, in contrast, large program efforts can lead to high contraceptive use, but the program efforts must be maintained at high levels to sustain high contraceptive use. Our empirical analyses of data in Malawi and Kenya have not indicated the presence of multiple equilibria in our data. Thus, these estimates suggest that there is little likelihood that a sharp transitory increase in program activities would lead to a rapid shift to much higher sustained levels of contraceptive use. But such possibilities may exist in other contexts.

Third, one can show formally that intensified social interactions may either increase or decrease the total effect and social multiplier effect resulting from family planning program efforts, and 'more' social interaction can thus reinforce or retard the diffusion of an innovation. When a nonlinear (logistic) model is used, increasing the impact of social interactions is status quo reinforcing close to a stable equilibria (whether at low or high contraceptive use) in a multiple-equilibria situation. Therefore, if a new program effort were to intensify social interactions near the stable equilibria, the total—or long-term—change in contraceptive use resulting from the program effort is reduced and these more intensive social interactions would retard the diffusion of family planning after the program interventions. Our nonlinear empirical estimates for Nyanza District in Kenya imply that when social interactions are intensified, they reduce the total effect associated with program interventions, but slightly increase the social multiplier effect. These findings are in contrast to the linear estimates that imply that more intense social interaction leads to a larger social multiplier effect and an increased total effect after the program interventions.

3.2 The Density of Social Networks and Fertility Decisions

In this section we turn to the specific mechanisms of how social interactions affect individual and population-level family planning use, and thus alter the potential interpretation of the effects of family planning programs,We turn to the specific mechanisms through which social interactions may affect fertility behaviors and contraceptive use. Early studies of this issue emphasized the content of social interactions, usually measured by the proportion of contraceptive users in a respondent's network, on family planning choices. These studies typically found that the probability of a woman's using contraceptives is related strongly to content, and that the relationship is positive: the more users in a network, the more likely that the woman herself uses family planning. in Kohler et al. (2001), in which study we expanded this approach by proposing that it is not just the number of users: rather, the structure of the network modifies the impact of the number of users in the network. Specifically, in these analyses we have included measures of network density, distinguishing between dense networks, in which all the network partners know each other, and sparse networks, in which the network partners are connected only through their ties to the respondent. The inclusion of network density allowed us to argue that when social learning dominates, network density should not matter. In situations of uncertainty, information is important. Because all members of a dense network are likely to possess the same information, we expect weak, possibly negative effects of density on the adoption decision when the content of the interaction is controlled. If social influence dominates, however, density is expected to be important. In particular, when the normative acceptability of contraceptive use is the issue, dense networks with a low proportion of contraceptive users should reduce the probability of using family planning; dense networks with a high proportion of users should increase that probability; and sparse networks should be relatively neutral.

In Kohler et al. (2001) we used this modeling approach and the KDICP data to estimate the probability of using modern contraception. The key empirical results are reported in Table 1. In addition to some standard socioeconomic characteristics, the estimated models in Table 1 include the proportion of contraceptive users in the social network, the density of the network, and an interaction between these measures of content and structure. We find that both our measure of network content and our measure of network structure are related to the probability that a woman uses family planning. The patterns of the interactions between content and structure in our empirical modeling, however, suggest that context determines whether social learning or social influence dominates. In one of the four regions of our study, Obisa, the probability of a woman's contraceptive use is affected primarily by the measure of the content of the interaction; network structure has little relevance. In Obisa, social learning apparently is the mechanism through which social interaction affects contraceptive decisions. In Owich, Kwadhgone and Wakula South (OKW), the other regions, it is not content but social influence that appears to be the primary mechanism through which networks influence individual behavior. In OKW, the interaction between content and structure is critical: dense networks discourage an individual from using contraception if the network includes few contraceptive users, but dense networks encourage use when contraceptive use in the network is relatively high. Thus, when social learning is the mechanism by which networks affect contraceptive decisions, a comparison across contexts confirms the simple account: the higher the proportion of contraceptive users in a woman's network, the more likely she is to use family planning. Where social influence dominates, however, the influence of networks is ambivalent: they may either facilitate or constrain the adoption of family planning.

These differential implications of social learning and social influence on the probability of using family planning are also depicted in Figure 3. Given the same social network, the ever-use of contraception is higher in Obisa than in OKW. If we compare the lines for dense networks and sparse networks in Obisa, we see that a woman is more likely to have ever-used modern contraception if she has a sparse network than if she has a dense network, given the same prevalence of family planning in a respondent's social network. Moreover, as the proportion of network partners using family planning increases, the lines diverge. Therefore, when the prevalence of users within the network is low, women with sparse networks are about as likely to use family planning as women with dense networks. When the prevalence of family planning in the network is high, however, women in sparse networks are more likely to use than women in dense networks. These patterns in Figure 3 for Obisa thus reflect the implications of social learning. In contrast, the right graph in Figure 3 reflects a relation that is typical for social influence. Although the probability of having ever-used contraception again increases with the prevalence of use among network partners, the effect is rather minimal and not substantively important for networks with a density of 0.5. Only for relatively dense networks (i.e., density > 0.75) does the proportion of contraceptive users in the network have a relevant influence on the respondent's probability to use family planning. In addition, the lines no longer diverge for increasing levels of contraceptive prevalence in the networks as in the left graph, but rather intersect at a prevalence of about 0.7 that is indicated by the line CC. To the left of the line CC an increasing density of the network reduces the probability of having ever-used contraception, holding the prevalence of family planning users in the network constant. To the right of the line CC the social influence is towards modern contraception. In this case, an increasing density of the network, holding the prevalence of contraceptive users in the network constant, increases the probability of using family planning.

These two regions for which our models are estimated in Table 1—Obisa and OKW-- are not distinguished by the characteristics of the networks of the respondents who live there, but rather by the extent of market activities: in Obisa, more women are engaged in market activities than in OKW, and they buy and sell at a larger market. We find that social influence is important only where market activity is low. Where market activity is high, social learning dominates. Although the available data do not allow us to investigate in detail the interdependence of social interaction and market activities, the notion that higher market activities favor social learning is plausible. After all, the spread of information is an important aspect of markets, and market participants may focus more strongly on the information provided by their personal contacts than on the social acceptance regarding their family planning behavior. Our findings about the importance of market activity are consistent with provincial differences in the onset and pace of fertility decline in Kenya: the earliest declines occurred in Nairobi Province and in Central Province. Markets in both of these locations have long been more highly developed than in Nyanza (Bates 1981). This finding also suggests that, even in areas where social interactions currently retard the diffusion of family planning, the dominance of conservative social influence may shift to a dominance of social learning, which will accelerate this diffusion if market development is sufficient.

3.3 Social Networks and Changes in Contraceptive Use Over Time

A limitation of the analyses in the previous section, as well as of much of the early demographic literature on social interactions, is that they do not permit confident inferences regarding the causal effects of social networks because unobserved factors that may directly affect attitudes and behavior may also directly affect choices of the units of social interaction (see our discussion above). Most of the literature on social interactions and demographic behaviors assumes, usually implicitly, that it is acceptable to treat networks as if they were formed randomly. There are at least two reasons to expect that this assumption of random network selection often may be violated. First, empirical studies suggest a nonrandom selection of network partners. For example, using qualitative data collected as part of the KDICP, Watkins and Warriner (2003) showed that the networks with whom respondents discuss issues of family planning and AIDS are characterized by a tendency to discuss these topics with others who are perceived to be similar ("*like me*"); in addition, some network partners are deliberately chosen because they are believed to have relevant information or competence. Second, a theoretical consideration of learning under uncertainty suggests that social interactions about family planning are determined by the following factors: (1) the costs and benefits of social learning about family planning and fertility-related issues; (2) the various social constraints imposed on the ability to engage in interactions about family planning due to the availability of suitable network partners and the social acceptability of communications about contraception and fertility reduction within households and communities; and (3) the expected reduction of uncertainty about the benefits, side-effects (or other costs) of using family planning through interactions with others, which depends in part on network partners' knowledge, their possibly strategic communication of this knowledge, and the individuals' interpretation of the information they obtain from others. As a result of these processes of how social networks are formed, if the causal direction is unclear, what has been interpreted as the causal effects of social networks may simply be associations that are due to both contraceptive use and network partners' choices being determined, in part, by unobserved factors, such as preferences related to contraceptive use and network partner selection. Therefore we use our longitudinal data with special information on social networks once again to investigate the determinants of contraceptive use in high-fertility rural Kenya.

Four major findings emerge from the analyses in Behrman et al. (2002) (see Table 2 for the key regression results). First and foremost, social networks have significant and substantial effects even when we controlled for unobserved factors that may also determine the nature of the social networks. In particular, this study provides what we believe are currently the best available estimates about the effects of social networks on contraceptive use in high-fertility areas. Second, estimates of the effects of social networks that are based on the implicit assumption that they are determined randomly, as in previous studies, may lead to a substantial misunderstanding of the impact of social networks on individual behaviors. With our data, analyses that did not control for the possibility that both contraceptive behavior and social networks within which this behavior is discussed are partially determined by unobserved factors, such as preferences, appeared to misestimate the effects of networks. Third, the effects of social networks are not limited to women, even though in local stereotypes women are often characterized as gossiping much more than men. To the contrary, our estimates indicate that, if anything, men are likely to be more influenced by their network partners than are women. This finding may reflect cultural patterns of exogamy and patrilocality that result in men having known their network partners since childhood, whereas women alter their network partners after marriage. Fourth, the effects of social networks that found in this study contribute to a better understanding of social change. These effects are generally nonlinear and asymmetric. They are particularly large for having at least one network partner who is perceived to be using contraceptives; however, the inclusion of additional network partners with the same characteristic generally has much smaller (and insignificant) effects (for women). This combination of nonlinearity and asymmetry suggests that the exchange of information constitutes the primary aspect of social interactions about family planning—social learning, not social influence. In addition, the nonlinear and asymmetric pattern of network influences is consistent with stereotypic diffusion models (Rogers 2003). If there are just a few who initially adopt an innovation, they have a relatively large influence because they interact with a relatively large number of individuals who have not yet adopted it; in such cases, they provide these individuals with at least one adopter, the influence of whom is relatively large. Thus, adoption initially accelerates. As there are more innovators, however, the marginal influence of yet another adopter eventually starts to decline. Interaction processes therefore suggest that social networks are likely to have large effects on behavior as long as an innovation is not widely disseminated. As innovative behavior increases, the marginal effect of interactions is likely to be much smaller than in the early phase of the diffusion process.

4 Social Networks and Mortality and Death—the Diffusion of Worry about AIDS

Individuals facing the tsunami of the AIDS epidemic in eastern and southern Africa know well that HIV is primarily transmitted in their context by sexual intercourse and that reducing risky sexual interactions can help to protect them from infection and death. Whether correct or incorrect, the subjective perceptions of one's own risk and of one's sexual partner's risk have been shown to be important correlates of whether an individual adopts risk-reduction strategies (Cerwonka et al. 2000; Estrin 1999; Weinstein and Nicolich 1993). But what is the process through which these risk perceptions are formed? (e.g., Smith 2003).[9] In Kohler et al. (2007), we therefore investigate the determinants of subjective HIV/AIDS risk assessments, focusing in particular on the hypothesis that individuals assess their risk of infection through interactions with others in their social networks.

4.1 Qualitative Evidence on the Content of Conversations about AIDS in Informal Social Networks in Malawi

We begin our discussion by drawing on qualitative data to provide insights into the process through which risk perceptions are formed in social networks. The first round of the MLSFH survey in 1998 had confirmed that respondents talked about AIDS with others in their social networks. These data, however, were inadequate for learning what people were saying to each other. For example, it could have been that there was no uncertainty about AIDS—perhaps all agreed or disagreed about the level of risk that they faced. Or perhaps the conversations did no more than transmit epidemiological information, such that HIV is transmitted sexually and invariably fatal, without comments evaluating the accuracy or appropriateness of the information, or that nothing was said in these conversations to support our assumption that social influence was being exerted in these conversations.

We thus conducted semi-structured interviews and ethnography in order to examine the validity of the assumptions with which we approached our quantitative analyses (see also Watkins 2004; Watkins and Swidler 2009, 2011). Here we draw on the ethnographies, the term we use to describe a large set of field journals collected since 1999. We asked a total of 23 high school graduates living in or near the MLSFH survey sites to pay attention to public conversations they heard about AIDS during the course of their everyday activities, such as walking to the well for water or having a beer in a local pub. They were then to write as much as they could recollect, and in as much detail as possible, in a field journal, which was then given to an intermediary and sent to us (for more detail see Watkins and Swidler 2009, see also details, are http://investinknowledge.org/projects/research/malawian_journals_project, for approximately 900 journals).

We begin by summarizing a journal that displays the great diversity in natural conversational settings and in topics covered in the conversations. The journal begins on the 14th of June, 2001, when the journalist, Alice, visits her cousin, who is a nurse at a hospital about an hour's bus-ride away. The cousin, who is pregnant, tells Alice that three months after her marriage her husband began coughing, then a headache, then diarrhea, then both diarrhea and shingles, all of which involved stays in the hospital. The cousin herself had become thin. The cousin requested that they both be tested, and both were HIV positive. Later, Alice returns for the husband's funeral, where she talks with her cousin and her cousin's mother. The cousin warns Alice, a widow, to be careful whom she marries, and to be sure to have a blood test beforehand. On the way home from the funeral, Alice meets a man at the bus stop who has been to see a brother ill with tuberculosis; he tells her that the TB ward is full, they all have AIDS (presumably including his brother). Another man at the bus stop joins the conversation, asking why it is that women appear to have AIDS more than men. This generates a lengthy discussion about differences in men's and women's behavior and bodies, whether or not it is possible to use a condom in marriage, medications, and the history of AIDS, with all of these topics introduced not by the journalist but by the men, none of whom Alice knows. Two weeks later Alice returns for the funeral of her cousin's newborn baby. Walking back from the funeral to the bus stop, a neighbor of her cousin asks Alice why her cousin is so thin, and then comments that people are saying she has AIDS because although she herself was innocent, her husband was promiscuous and, as a woman, she could not refuse to have sex with her husband. On the bus, a woman starts a conversation with Alice about AIDS, which is then joined by the third person on their seat, an old man. Again, the others introduce the topics, which cover AIDS as God's punishment, AIDS as witchcraft, AIDS as a governmental plot, and AIDS as a result of youth who disobey the advice of their parents. A few weeks later Alice goes to the funeral of her cousin, where she overhears others explaining that her cousin was the innocent victim of her husband.

Although funerals are frequent in rural Malawi—the 1998 survey round showed that on average respondents went to 3-4 funerals a month—the scarcity of facilities of HIV testing at that time in rural Malawi meant that few would have been tested. Nonetheless, by that time people knew the symptoms of HIV, which they combined with local knowledge about the medical history of the deceased and his or her sexual biography to conduct a "*social inquest*" on the cause of death. Seeing someone sicken and then die of something that was believed to be AIDS is likely to have influenced the formation of individual's own perception of risk, the variable that in our quantitative analysis below is summarized as "*worry*" about infection.

In one incident, a young man tells several friends that he has reformed his behavior. They ask why, and he explains: "*Only because I have seen for myself, some of my friends have died because of this disease AIDS, and I do care for my life. AIDS troubles a lot! I didn't say anything. He kept on, saying, For example, there was a certain army pensioner who was living up there in my village.... He was very sick indeed, going to the hospital, no treatment, private hospitals—just wasting money and then he came home and was sick until he became like a very little young child. I was going to see him during the whole course of his suffering. You could liken him to a two-year-old child when he lay down sick.... And the way I had seen him suffering, that's when I came to my senses, that indeed AIDS troubles a great deal before one dies.*"

The young man attributes his behavioral change to seeing a neighbor who he knew had many sex partners decline physically, but we know from other journals that this witness had himself been promiscuous. Thus, it is likely that while watching his neighbor waste away he imagined himself as "*a two year-old child*." We do not know whether the reforms he claimed to have made happened at all, or persisted, or occurred too late. We do know that many in Malawi have had similar experiences watching those with whom they can identify die, as well as hearing about other deaths they did not witness. If we are persuaded by the literature in psychology that "*people disproportionately weight salient, memorable or vivid evidence even when they have better sources of information*" (Rabin 1998: 30, citing Kahneman and Tversky (1973)), then anecdotes about people who are known in the community are likely to weigh heavily in the process of perceived risk formation, as well as to provide particularly compelling motivations for change.

Rarely is information about HIV or AIDS unaccompanied by comment. The information is often evaluated in terms of its credibility. For example, one conversation turned to the possibility of infection when a man gets his hair cut from a barber. A woman says going to a barber is dangerous, that she heard a radio program that if a person with HIV is cut, "*the virus sticks to the teeth of the shaver and if other people come to be shaved ... definitely the other people will contract the virus and start suffering from AIDS*." Another participant, however, evaluates this information by offering a counterfactual: he says "*then if what the government was saying through the radio, that Barber shops can also facilitate the spreading of the virus which causes AIDS, was true, a lot of people would have contracted it, almost every man starting from a young boy and men and some of the women and girls.*"

People also share their personal worries with others. For example, while walking together to a funeral one woman tells two others that she is worried that her husband will give her AIDS, for he had been having an affair with the deceased, a known prostitute who was believed to have certainly died of AIDS.

Now, she says, she doesn't know what to do. The participants discuss the pros and cons of divorce: the conversation ends when one of the participants advises her to have a blood test before she takes a hasty action.

In addition to providing insight into the process by which perceptions of risk are formed in social networks, the above qualitative findings emphasize that many determinants of risk assessment are likely to be unobserved in survey data, including for instance aspects such as an individual's exposure to seeing someone die from AIDS, or being advised to have a blood test before taking the serious step of ending a marriage. These unobserved factors are not only important because they are prone to affect variation in perceptions of risk, but also the size, composition, and selection of individuals' social network partners. Some individuals, for example, are likely to have less tolerance for risk and, because of systematic patterns in the selection of their social networks, are more likely to associate with others who have less tolerance for risk (for a discussion of these aspects of social network selection, see also Behrman et al. 2002; Manski 2000; Watkins and Warriner 2003). Based on considerations above about individuals having unobserved characteristics such as those related to risk aversion and social interaction that are likely to affect both their worry about HIV/AIDS and their social networks related to information about HIV/AIDS, parallel to our studies of the impact of social networks on fertility control in Section 3, we posit that prior social networks are not likely to be random in the sense of being independent of disturbance terms in relations for the estimation of risk perceptions and AIDS-related behaviors at time t. Therefore we use an empirical specification of the relation determining risk perceptions and AIDS-related behaviors in which there is explicit recognition that, in addition to observed right-side variables (including social networks prior to time t, there are unobserved factors.

4.2 Quantitative Evidence on the Impact of Social Networks on Responses to AIDS

Not surprisingly, concerns about the risk of AIDS infection were widespread in both rural Kenya and Malawi from the mid- to late 1990s onward. The MLSFH survey measured this perceived AIDS risk with a question frequently used in research on risk perceptions: "*How worried are you that you might catch AIDS?*" Responses to this question ranged from "*not worried at all*" to "*worried a lot.*" Between 36% and 40% of women in Kenya responded in the 1996/1997 (KDICP 1) and 2000 (KDICP 2) surveys, respectively, that they perceived themselves to have a moderate or high risk of becoming infected with AIDS. For Malawi, 61% and 47% of women perceived a high risk of AIDS in 1998 (MLSFH 1) and 2001 (MLSFH 2), respectively; moreover, their responses are highly and positively correlated with a question about the subjective likelihood that the respondent will become infected with HIV in the future. Respondents were generally also aware of several mechanisms by which HIV/AIDS is transmitted and several means of protection. For instance, in 1996/1997, more than 90% of women in Kenya knew that AIDS can be transmitted by sex, and 48% knew about possible transmission by injections. Similarly high levels of knowledge prevailed in Malawi.

Survey responses in the KDICP and the MLSFH reinforce the perception from the qualitative data that such conversations are frequent. In both the KDICP and the MLSFH, the survey module for collecting the egocentric network data on HIV/AIDS conversations began with a question "*How many people have you talked with about AIDS?*" Very few had talked with no one. The networks are quite dense (most members know each other as well as the respondent) and highly gendered (men talk with men, women with women) (Watkins and Warriner 2003; Zulu and Chepngeno 2003). Responses to other questions provide insight into some topics of their conversations. For example, respondents report on the extramarital partnerships of their network partners and their best friend; a study of a subsample of MLSFH respondents shows that they learn about these relationships directly from one of the couple, in-directly from others who have talked with one of the couple, or from observation ("*I saw them coming and going*" (Tawfik and Watkins 2007). More than 85% (Kenya) and 87% (Malawi) of women know of at least one recent death that they suspected was caused by AIDS, and more than 30% (Kenya) and 16% (Malawi) know about more than five such cases. The specific question in the KDICP and MLSFH regarding the risk perceptions of the network partners was phrased as "*How worried is name of network partner about getting AIDS?*," with the same response categories as for the respondent. Over three-quarters of the women had talked with at least one person about AIDS, and over two-fifths of the women had talked with at least one person who believes that he or she is at moderate or great risk of becoming infected with AIDS. Interestingly, between the 1998 and 2001 rounds of the MDICP, women who were married in the former but divorced or widowed in the latter became less worried about infection, whereas those who were not currently married in 1998 but had married by 2001 were more worried (Smith and Watkins 2005; see also Reniers 2008). In addition to talking with network partners about AIDS, husbands and wives discuss with each other their risks and how they can prevent infection; following HIV testing conducted by the MDICP in 2004, 84.4% of women and 91.9% of men reported having shared their HIV test result with their spouse (Anglewicz and Chinsanya 2011).

On average, women reported in the KDICP 2&3 and the MLSFH 1&2 surveys that they had talked with 3.9–4.8 network partners about AIDS, and men report slightly more interactions, ranging from close to 4 to about 7 network partners. Detailed information about interactions is available for about 2.4–3.6 network partners. In general, the respondents report more interactions with network partners who perceive high AIDS risks as compared with network partners who assess their risks as low. Neither the size of these networks nor having talked with at least one network partner about AIDS depend strongly on the respondent's risk perception (Kohler et al. 2007, Table 3), whereas—as we expect based on the our hypothesis that social interactions are important determinants of risk perceptions—network partner's assessments of HIV/AIDS risks are associated with the respondent's own risk perception. We represent social networks by the extent to which each respondent's network partners are reported to be worried about AIDS. This perception is measured via a categorical variable with four options in Kenya (categories are none (1), some (2), moderate (3), and great (4)) and with three options in Malawi (categories are none (1), moderate (2), and great (3)). The essential variable representing social interactions about HIV/AIDS is therefore the number of network partners with whom the respondent has interacted about HIV/AIDS classified by the respondents' perceived network partners' risk perceptions. Although in what follows we will refer to the network partners' perceptions of risk, these perceptions are reported by the respondent.

The linear social interaction model discussed above provides one possible framework for empirically analyzing the effect of social interactions on the perceived risk of AIDS, where Y^{it} is redefined to be the perceived AIDS risk of individual i at time t, f_i represents the unobserved fixed factors that are assumed to affect risk perceptions and AIDS-related behaviors by individual i (e.g., the persistent part of preferences, unobserved current community characteristics, expectations regarding future prices, and interfamilial and community resources on which the individual can draw), and e_{it} is an i.i.d. disturbance term that affects the perceived AIDS risk of individual i at time t due to, for example, new information about AIDS prevalence provided by the death of a family/community member from AIDS, new information about the behavior or the spouse, or price shocks that are deviations from the long-run secular price trends.

As discussed above in the context of estimating social interaction effects for the adoption of family planning, in order to obtain consistent estimates of the coefficient a, which measures the impact of social networks on risk perceptions and AIDS-related behaviors, it is necessary to break the correlation between the term representing social networks (N_{it-}) and the compound disturbance term including both fixed and random elements ($f_i + e_{it}$). However, contrary to our earlier example, a fixed-effect estimation alone may not be fully satisfactory because it relies on the assumption that the social network prior to time t, N_{it-}, does not depend on the lagged disturbance terms $e_{i(t-1)}$ (or higher-order lags). Our estimation strategy in Kohler et al. (2007) allows for such feedback from lagged disturbances affecting HIV/AIDS risk perceptions on the current social network size and composition by combining fixed-effect and instrumental-variable (IV) estimation. Since differencing over time eliminates the individual fixed effect f_i from the estimation relation, variables that are correlated with the fixed effect but uncorrelated with the difference of e_{it} over time can be used as instruments. Specifically, our analyses in Kohler et al. (2007) use the initial "*stock*" of social network partners observed in KDICP 2 or MLSFH 1, funerals and other events that led to social gatherings, and other "*stock variables*" at the beginning of the panel such as age, education, marital status, and indicators of household wealth.

To demonstrate empirically the relevance of considering the endogeneity of social networks in inferences of social interaction effects, we implemented the following four estimation techniques: (a) standard OLS analyses; (b) fixed-effect estimation; (c) IV fixed-effect estimation that instruments for the change in the social network measures, ΔN_{it-}; and (d) Generalized Methods of Moments IV (GMM-IV) fixed-effect estimation, which uses a more efficient weighting of the moment conditions implied by the IV fixed-effect estimation (Baum et al. 2003; Hayashi 2000).

The regression results for women are shown in Table 3, with additional results reported in Kohler et al. (2007). In summary, the key findings of the analyses can be summarized as follows: First and foremost, the analyses show that social networks have significant and substantial effects on individuals' AIDS risk perceptions, even when we control for unobserved factors that also may determine the nature of the social networks. Thus, to understand the dynamics and diffusion of behavioral change in response to AIDS, it is essential to incorporate the impact of social networks: the failure to do so may lead to misunderstanding the dynamics of behavioral change. Second, this effect of social networks extends to the area of spousal communication about AIDS risk, and interactions with network partners—independent of network partners' risk assessments—tend to increase the probability of husband-wife communication about the disease. Third, the effects of social networks found in this study contribute to a better understanding of diffusion. These effects are generally nonlinear and asymmetric. They are particularly large for having at least one network partner who is perceived to have a great deal of concern about AIDS. The inclusion of additional network partners with the same level of concern or with less concern generally has much smaller or insignificant effects. An exception to this asymmetry occurs in the network effects on spousal communication: network partners, independent of their risk perceptions, have strong and significant effects. Fourth, social networks are associated with important social-multiplier effects that reinforce the effects of AIDS prevention programs. For women, for instance, about one-fifth of the influence of program efforts on respondents' HIV/AIDS risk perceptions is mediated through social networks.

These findings are of central importance for understanding the spread of AIDS because they document that social interactions constitute important determinants of how individuals and couples develop strategies for coping with the disease. In particular, this study shows that social networks exert systematic and strong influences on risk perceptions and the probability of spousal communication about

IDS risks in rural areas of two sub-Saharan African countries with high HIV prevalence, and that these influences are in addition to other factors such as program interventions that disseminate knowledge about the disease, provide access to condoms, and advocate changes in sexual behaviors within and outside marriage. Social networks are also likely to amplify program efforts aimed at increasing individuals' information about HIV/AIDS and their assessments of their own risks. Thus, social interactions are likely to have a substantial impact on the course of the epidemic and the magnitude of its consequences, and these should be taken into consideration in understanding and predicting behaviors in such high-prevalence contexts and in devising program interventions with respect to the HIV/AIDS epidemic.

5 Sexual networks and HIV/AIDS: The Likoma Network Study

Sexual networks are the primary mechanism through which HIV is spread and transformed in Sub-Saharan Africa (SSA). Theoretical network models have shown that individuals' positions within these sexual networks, and the structural characteristics of the network itself, are important determinants of HIV infection risks and disease dynamics (Ghani and Garnett 2000; Kretzschmar and Morris 1996; Newman 2002). Despite this evidence, empirical network studies of HIV infection risks and disease dynamics in SSA remain very limited. Available data on sexual networks are often based on small populations, frequently restricted to ego-centric rather than complete networks, and with the exception of the study described in this paper, not based on an integrated design that includes tracing of sexual networks, HIV testing, and extensive socioeconomic data for all members of a population.

In a pioneering illustration of the interactions between networks and health in a poor developing country, the Likoma Network Study (LNS) represents the first complete sexual network data for a large population – that on Likoma Island, Lake Malawi. Combining a census of the population with a sociocentric sexual network survey of *all* adults aged 18–35, Helleringer and Kohler (2007) document the existence of a large and robust sexual network (Figure 4). Half of all sexually active respondents were linked together in a *giant network component*, and more than one quarter were connected together through multiple independent chains of sexual relations. Such structural features of sexual networks have been associated with epidemic spread of STIs in high-risk groups, but prior to this study had never been documented among the general population. This unique design of the LNS has provided important new findings on the role of concurrency of sexual partners and HIV risk, the role of migrants and the contribution to HIV risks within rural populations, the uneven distribution of HIV risks within large sexual networks, data quality and misreporting of sexual relationships, and the determinants of sexual relationships and patterns of homophily and clustering within sexual networks (Helleringer and Kohler 2008; Helleringer et al. 2007, 2009a,b,c).

Epidemics in a mathematical sense are nonlinear phenomena. The classical models of mathematical epidemiology rely on the assumption that sexual partners are randomly selected (i.e., the population is assumed to be well-mixed and unstructured) (e.g., Anderson and May 1991; Bailey 1975). In this framework, two key measures to study epidemics are (1) the basic reproduction number, R_0, and (2) the final size of an epidemic s_∞. The basic reproduction number, R_0, is the expected number of secondary infections arising from a single, typical infectious individual in a completely susceptible population (Heesterbeek 2002). In a well-mixed and socially unstructured population (i.e., where individuals randomly select their partners from other members of the population), R_0 is the product of three quantities: the transmissibility of the infection τ, the duration of infectiousness δ, and the rate of contact between susceptible and infectious individuals c. When $R_0 > 1$, an epidemic is certain in a deterministic model and has non-zero probability in a stochastic model. Strategies for disease control and eradication are aimed at bringing R_0 below the threshold of unity, i.e, when the average infection generates fewer secondary infections than necessary for replacement and the epidemic fades. In the well-mixed and unstructured case, the final size of the epidemic is given by the implicit equation $\log(s_\infty) = R_0(s_\infty - 1)$, which has exactly two roots on the interval [0 1] when $R_0 > 1$. The smaller of these roots is the proportion of the population remaining uninfected at the end of an epidemic.

Because HIV is transmitted by intimate sexual contacts between partners, and because people employ varied and elaborate rules to choose their partners (Magruder 2008; Watkins 2004), HIV transmission dynamics in real populations are not well described by the classical epidemiological model. In other terms, c is generally a poor approximation of the patterns of contacts leading to the diffusion of an infection within a population. For instance, while African men (and to a lesser extent, women) do not report having more sexual partners than men elsewhere, they tend to have more than one on-going long-term relation at any point in time. Partnerships in SSA can overlap for months, maybe years (Lagarde et al. 2001; Morris and Kretzschmar 2000). This pattern of sexual partnerships that overlap rather than follow each other sequentially, is one of several important characteristics of human sexual networks that violate the classical epidemiological model and importantly affect HIV infection risks and disease dynamics (Kretzschmar and Morris 1996; Moody 2002). *Concurrent partnerships* may thus increase the speed at which HIV spreads through a population, and have probably contributed to the rapid take-off of the HIV epidemic in SSA in the 1980s (Morris and Kretzschmar 2000). Other violations of the classical epidemiological model include: (1) *assortative mixing*, i.e., the selection of sexual partners based on their individual characteristics, can structure a network into communities within which the disease spreads rapidly, but across which the spread is slow (Laumann et al. 1994; Laumann and Youm 1999; Morris 1993); (2) *small worlds*, i.e., networks characterized by bridges joining otherwise disjoint clusters (Watts 1999; Watts and Strogatz 1998), can lead to thresholds and rapid disease diffusion to distant subpopulations; (3) *robust networks*, i.e., groups of persons tied together by more than one path in the sexual network, can decrease the ability to control the spread of HIV because redundant connections continue to transmit HIV even after some transmission paths are broken or eliminated (Potterat et al. 2002); (4) *skewed degree distributions*, i.e., networks containing individuals with a very high number of partners (high degree network members), can result in epidemics driven by promiscuous individuals.[10]

While it is possible to simulate HIV disease dynamics taking these characteristics of human sexual networks into account (Hethcote et al. 1991), only detailed information on the sexual network structures in SSA allows proper calibration of these models. In addition, the investigation of sexual networks has important implications for disease prevention. For instance, in a simple heterogeneous epidemic model structured by degree of sexual activity, the basic reproduction number, and therefore epidemic threshold, is linearly proportional to the variance in partner numbers (e.g., Anderson and May 1991; Bailey 1975). Epidemics will therefore be more difficult to control in populations characterized by behavioral heterogeneity. The structure of sexual relations between the highest degree individuals and the general population will also determine the effectiveness of control interventions. The design of optimal interventions to control HIV therefore need to take the prevailing sexual network structure into account. However little is known about these aspects due to the lack of detailed sexual network data.

The literature therefore suggests a considerable potential for important and policy-relevant research based on an empirical investigation of the relationships between sexual networks, HIV infection risks, and HIV/AIDS disease dynamics. While sophisticated analytic methods have recently become available that allow these investigations (e.g., Koehly and Morris 2004, Goodreau, et al. 2009), their application to high HIV-prevalence contexts in SSA has been hampered by a lack of suitable data. This is not surprising, as the empirical challenges are formidable: (*i*) network information needs to extend to (quasi) complete networks, including information on the structure of the network and the positions of individuals within the network; and (*ii*) data need to be comprehensive, ranging from sexual networks to risk perceptions, sexual behaviors and health measures, and be available for *both* respondents and their network partners.

The Likoma Network Study utilizes a sociocentric design to address many of these concerns (see Section 2 for a discussion of the data collection. Among the 1,858 reports of sexual relationships that were collected during the first round of the LNS, 1,333 (72.7%) were to partners currently residing in Likoma, and 845 (45.5%) were to partners who were also interviewed during the ACASI survey. The reliability of the reports of these within-sample sexual relationships is relatively high as 57.8% are reported jointly by both partners, with marital relationships being substantially more reliable than non-marital relationships. Based on these reports, we reconstructed a large sexual network including 1,803 individuals: 923 respondents of the sexual network survey and 880 sexual partners of respondents who were not interviewed. These network members are connected by 1,614 unique sexual relationships as a total of 244 relationships among survey respondents were concordantly reported by both partners. Several key findings emerge from this study of sexual networks in Likoma (Figure 4):

Component size distribution: The sexual network identified by this study contains a total of 256 separate component representing clusters of individuals who are connected through each other through sexual relations that have occurred during a 3-year period prior to the survey. The distribution of component sizes is highly skewed: more than 86% of the identified components are of size five or smaller, but include only 34% of all sexually active respondents. On the other hand, two thirds of network members are embedded in 35 components of size six or larger that are shown in Figure 4. Moreover, 883 network members—56% of male and 45.6% of female survey respondents—constitute a single giant component of individuals connected through sexual partnerships having taken place during the three years prior to the survey. Inclusion in this component is not necessarily associated with a large numbers of partners: whereas members of the giant component on average reported a higher number of partners than other respondents (3 vs. 1.8, $p < 0.01$), a substantial fraction of members of the giant component (40%) also had at most 2 partners during the three years prior to the survey. The connectivity of the sexual network therefore occurs not because the distribution of the number of sexual partners is highly skewed (i.e., a small number of individuals are network "hubs" because they have high rates of multiple partnerships (Liljeros et al. 2001), but as a result of a generally moderate number of relationships with partners who have (or have had) other partners, who in turn may have had other partners and so on. When we restrict the period of observation to the year prior to the survey, a larger proportion of network members are included in dyads (28.2%) (Figure 5). Nevertheless, large connected components still emerge within the network: close to half of all network members belong to components of size 4 and above, and close to one quarter of all network members are included in structures of size 25 and larger.

High prevalence of cycles in the network: The giant component dominating the sexual network among young adults in the study villages (Figure 4) also contains three *bicomponents* that include individuals who are connected by more than one independent path. Two of these bicomponents are simple diamonds connecting four network members in a cycle. The third bicomponent, however, is significantly larger and includes 274 individuals, that is, 15% of all members of the sexual network and close to 25% of survey respondents. Among respondents below age 25, 36% belong to this denser region of the network. Several young adults in our study villages have had more than one partner in common, and a significant proportion of inhabitants of Likoma may be at an increased risk of HIV infection because they are connected by multiple independent chains of sexual relations. Moreover, the occurrence of cyclical structures in the observed sexual network does not depend on the relatively long recall period of three years: the bicomponents in Figure 4 contain cycles even if only recent or currently active relationships are considered. For instance, the network of relationships that were active within one year of the survey contains several bicomponents connecting a total of 84 network members (Figure 5a). Short-length cycles (i.e. two individuals having two partners in common) are also present within the network of relationships that were ongoing at the time of the survey (Figure 5b). For comparison, Bearman et al. (2004) did not find any short-length cycles among students of a US high school over an 18 months period.

Network location and HIV infection: Analyzes of the position of HIV-positive individuals within the network indicate that the distribution of HIV is not homogeneous (Table 4), ranging from 3% in the bicomponents to 8.9% in the disjoint components and 10.8% in the branches of the giant component. While members of the bicomponents (Figure 4) are exposed to multiple pathways of potential HIV infection, HIV prevalence is highest in the sparser regions of the network—i.e., small components and the giant component outside the bicomponents. Several factors contribute to this apparently paradoxical distribution of HIV prevalence. First, the sociodemographic composition of the sparser regions of the network favors an increased prevalence of HIV as some groups who are more likely to be infected—e.g., older respondents, women and widows—are over-represented in these regions. Second, the prevalence of several risk factors associated with HIV infection also varied significantly within the network (Table 4). For instance, the proportion of respondents having engaged in relationships outside of Likoma, or having engaged in a relationship with a partner older than 30 years, were higher in the sparser regions of the network. Relationships—in particular marital relationships—tend to be longer in the smaller components, and as a result concurrent partnerships might actually be more common in these structures. Table 4 also shows that the participation in HIV testing differed across regions of the network, but this modest variation is unlikely to explain the differential HIV prevalence across regions of the network.

6 Conclusions

Social networks receive an increasing emphasis in theories of fertility change, and sexual networks have emerged as an important research theme for understanding the spread of HIV/AIDS. This interest in social and sexual network studies in demography has a pedigree in anthropology, sociology, economics and epidemiology, and there is related contemporary work in all of these disciplines.

Our work for well over a decade in investigating the roles of interactions in social—and more recently also sexual—networks for important demographic behaviors has been based on data collected in Kenya and Malawi. This paper began by reviewing the theoretical arguments regarding why an explicit consideration of social/sexual networks is relevant for understanding fertility and health behavior, and how interactions in social or sexual networks can affect the aggregate dynamics of fertility change or diseases such as HIV/AIDS. We then discussed some of the empirical challenges and approaches to collecting egocentric and sociocentric network data, and we illustrate some of the methodological challenges in using such data to establish causal relationships between social interactions and individual behaviors. And finally, this paper reviewed several analyses that have investigated the role of social networks in the diffusion of fertility control and in shaping perceptions about HIV/AIDS, and we discuss some of the key findings of the Likoma Network Study (LNS) that has provided the first large-scale sociocentric sexual network study in a high HIV prevalence context in sub-Saharan Africa.

Notes

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[1]Other data sets on AIDS have information on respondents' sexual partners (information that we do not have for our overall samples, though we do have for some subsamples) but not on their social networks in which they discuss HIV/AIDS risks and ways of coping with such risks.

[2]The question about the number of conversations did not have an explicit time reference. A related question in the Kenyan survey about the time of the last conversation shows that many conversations were relatively recent: the last conversation with the network partner occurred within one year prior to the survey in more than 80% of all cases. We expect that this pattern is similar in Malawi.

[3]Likoma extends over only 18 square kilometers, has limited transportation to the mainland, and its population is small with just over 7,000 persons living in a dozen villages.

[4]The assumption that the disturbance term e_{it} is i.i.d. also excludes autocorrelation; the model therefore assumes that persistent heterogeneity in contraceptive behaviors among individuals with similar observed characteristics is primarily due to heterogeneity in fixed characteristics (captured by the fixed effect, f_i) rather than to lasting effects of past "*shocks*" (captured by lagged values of the disturbance term e_{it})

[5]Fixed effects estimates control for unobserved fixed factors, but not for unobserved time-varying factors (see Section 4.2 below).

[6]For simplicity, in our discussion of this theoretical model in this section (but not in our estimates discussed below) we consider only women who are identical with respect to individual characteristics, which permits us to combine the effect of these characteristics into the constant term d.

[7]That is, if the social multiplier is 175%, the proportion of the total effect due to social interaction is 75/175.

[8]Related models of multiple equilibria and path dependency in the context of fertility decline are found in, for example, Becker et al. (1990), Galor and Weil (1996) and Kohler (1997, 2000).

[9]For a general discussion of the need to better understand the formation of expectations, including risk perceptions, see Manski (2004). Some of the few studies that explicitly address the determinants of AIDS risk perceptions in sub-Saharan Africa or other developing countries are Bernardi (2002); Bühler and Kohler (2003); Bunnel (1996); Helleringer and Kohler (2005); Kengeya-Kayondo et al. (1999); London and Aroyds (2000); Smith (2003); Smith and Watkins (2005); Watkins (2004).

[10]E.g., Liljeros et al. (2001); for a critical perspective, see Handcock and Jones (2004); Jones and Handcock (2003).

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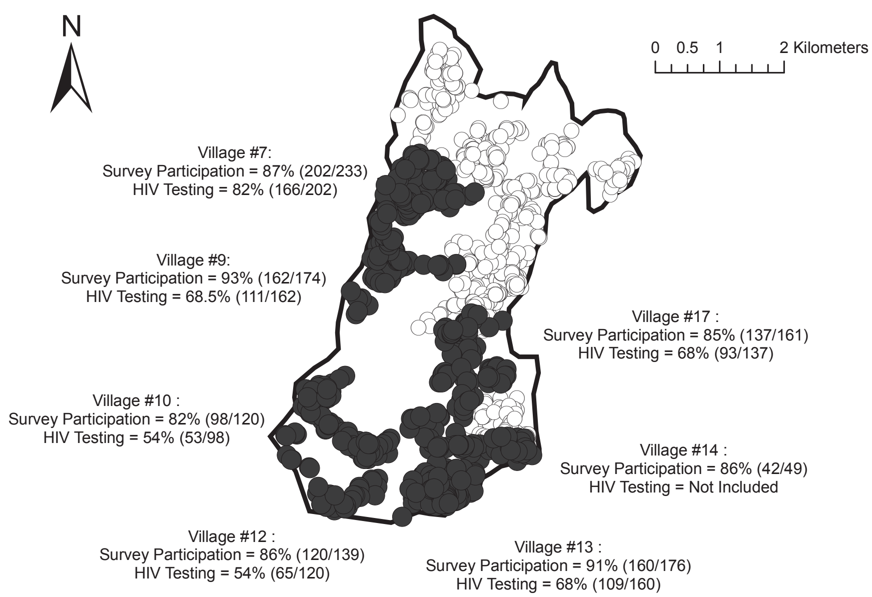


Figure 1: Geographic location of the sampled villages and village-specific participation rates. Each circle represents a dwelling unit. Dark circles represent dwelling units in the villages that were included in the sexual network survey. Empty circles represent dwelling units in the villages that were not included in this sampling frame. Denominators of the survey participation rates are the total number of eligible respondents (aged 18–35 and their spouses) in a given village, based on the initial household census. Denominators of the HIV testing participation rates are the total number of respondents who completed the sexual network survey in a given village. Island boundaries and location of dwelling units are approximate.

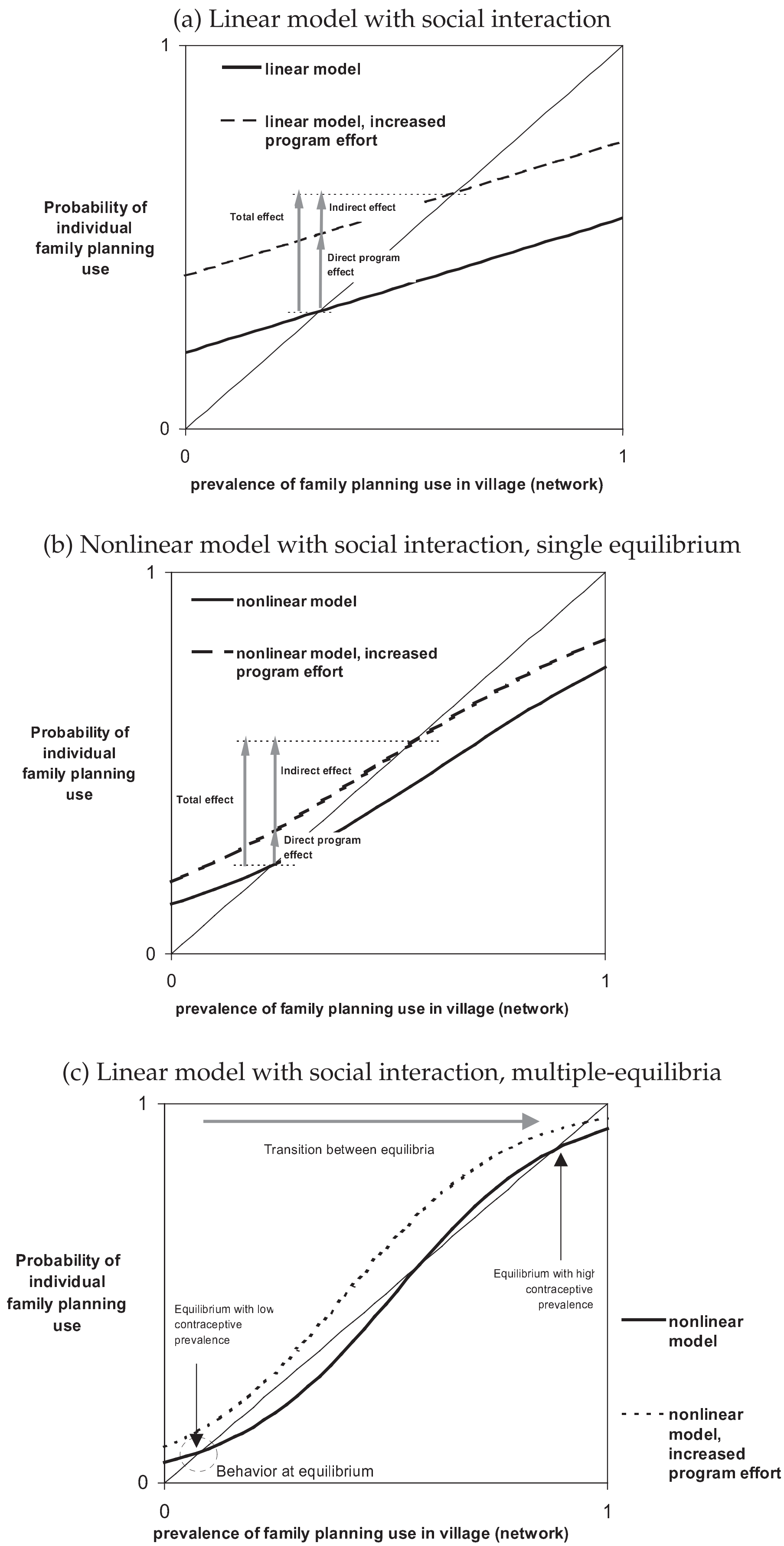


Figure 2: Linear and nonlinear model with social interaction

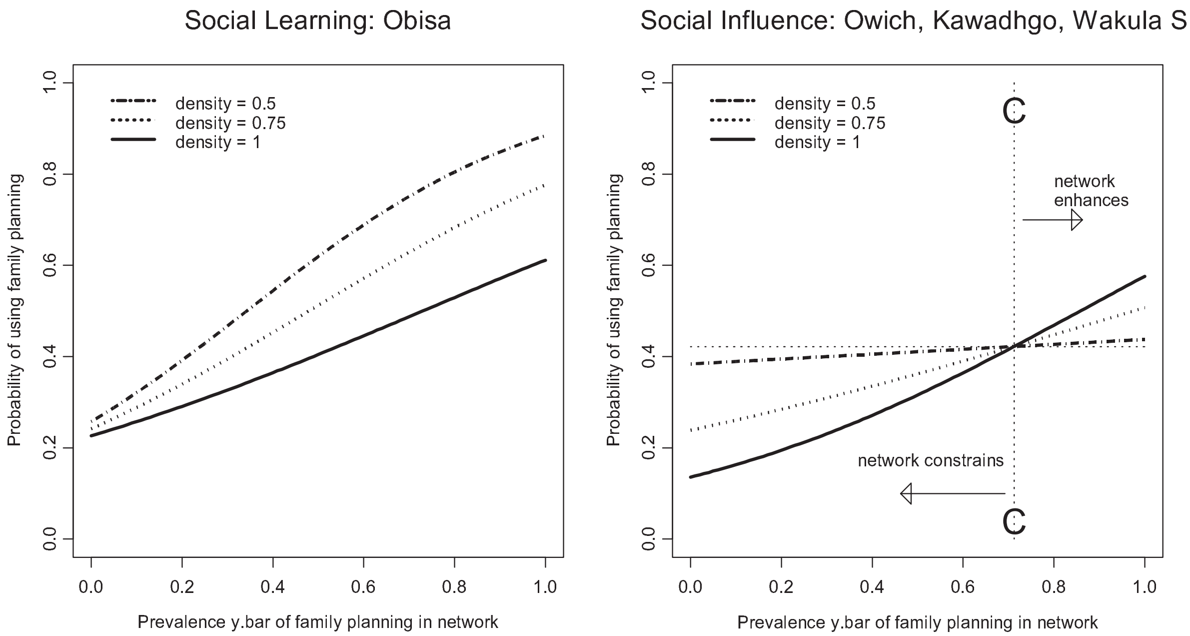


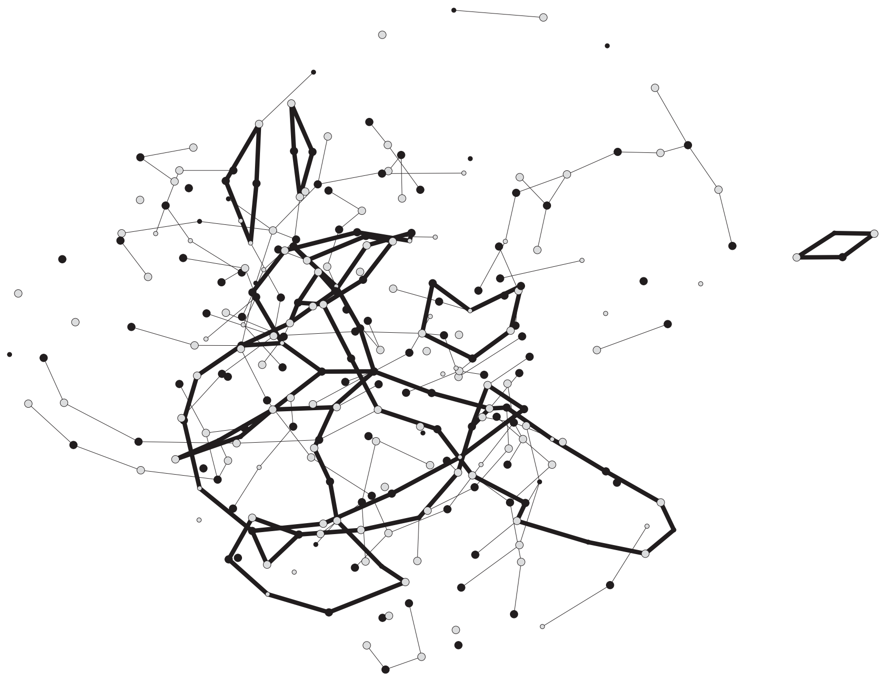
Figure 3: The effect of contraceptive prevalence in the network on the probability of adopting family planning for respondents with networks of different density (parameter values are derived from Model 3 in Table 1)

The graph is based on a nonlinear behavioral model in which the probability of a woman choosing modern contraception is $\Pr(y = 1|\bar{y}_{nw}, x, D_{nw}) = F(\alpha(D_{nw})(-\phi + \bar{y}_{nw}) + \beta x + \gamma)$, where F is the cumulative logistic distribution, and direction of the network effect towards using or not-using family planning is determined by a social utility term $\alpha(D_{nw})(-\phi + \bar{y}_{nw})$. If the proportion of network partners who use modern contraception $\bar{y}_{nw}$ exceeds a critical level ϕ, then $(-\phi + \bar{y}_{nw}) > 0$ and the social network favors the adoption of family planning; the term $\alpha(D_{nw})$, which depends on the density of a network, determines the strength of this social influence. If $\bar{y}_{nw}$ is lower than ϕ, then $(-\phi + \bar{y}_{nw}) < 0$ and social interaction influences a woman's decision towards not using contraception. The influence is stronger the more $\bar{y}_{nw}$ deviates from the 'neutral' level ϕ: when $\bar{y}_{nw} = \phi$, then network effects on contraceptive adoption are absent and the respondent's decision is not affected by the presence of social interaction. This behavioral model translates into our estimates in Table 1 when a linear model for $\alpha(D_{nw})$ is specified, where $\alpha(D_{nw}) = \tilde{\alpha}_1 + \tilde{\alpha}_2 D_{nw}$.

Figure 4: Components of the Likoma sexual networks of size six and larger: All sexual relationships in components of size 6 or larger that were ever active during the 3 years prior to the survey

Circles represent individuals. Lines represent sexual partnerships between individuals. Black circles: male survey respondents; gray circles: female survey respondents. Larger circles represent network members who were interviewed during the sexual network survey and who were sexually active during the recall period ($n = 896$). Smaller circles represent network members who were found within the village rosters but were not interviewed because they were outside the sampling frame of this study (= *all* young adults aged 18–35 and their spouses living in the seven sample villages shown in Figure 1). The subset of lines not connecting two circles represent partnerships with individuals we were not able to identify in the rosters of potential partners. The subset of thicker lines represent partnerships within bicomponents, i.e., between network members who are connected by more than one independent pathway within the sexual network.

(a) within 1 year prior to survey



(b) at time of survey

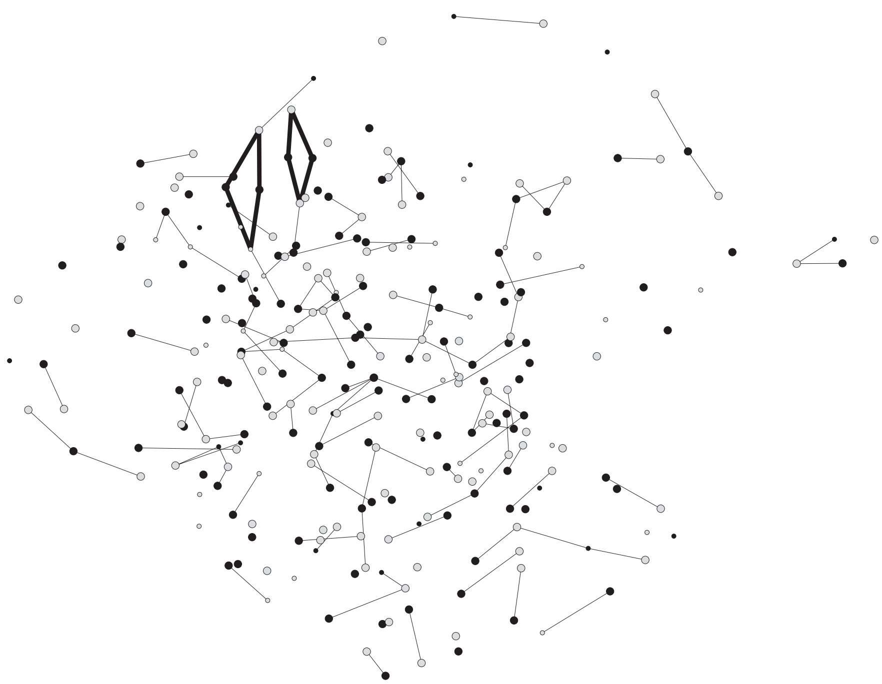


Figure 5: Relationships within the bicomponents of Figure 4 that were active within 1 year prior to the LNS network survey (top panel) and at the time of the survey (bottom panel)

Table 1: Logistic regression of contraceptive use (ever used family planning) on individual and network characteristics (Sample: currently married women with a family planning network of size three or four)

	Model 1	Model 2	Model 3
for Owich, Kawadhgo and Wakula S.			
%users (δ_1)	1.619	1.596	-1.712
	(0.442)**	(0.442)**	(1.053)
density (δ_2)		-0.248	-2.756
		(0.531)	(0.787)**
density $\times$ *%users* (δ_3)			3.867[a]
			(1.268)**
for Obisa			
%users (δ_1)	2.271	2.290	4.495
	(0.623)**	(0.542)**	(2.197)*
density (δ_2)		-1.850	-0.337
		(0.831)*	(1.654)
density $\times$ *%users* (δ_3)			-2.814[a,b]
			(2.614)

Notes: The estimated model is specified as $\Pr(y = 1|X, \textit{social network}) = X\beta + \delta_1 \cdot (\%\textit{users}) + \delta_2 \cdot \textit{density} + \delta_3 \cdot (\%\textit{users}) \cdot \textit{density}$, where y equals 1 if the respondent uses (has ever used) family planning, X is a set of individual characteristics, *%users* is the percentage of users of modern methods of family planning by the network partners, and *density* is the density of the social relations among the network partners. The individual characteristics included in X include age, age^2, number of children ever born, and dummy variables indicating whether the respondent has primary or secondary education. The standard errors, reported in parentheses, are adjusted for the clustering of respondents in villages using the Huber- White estimator of variance. *p-values:* * $p < 0.05$; ** $p < 0.01$. *Additional tests:* (*a*) The linear combination $\delta_1 + \delta_3$ measures the effect on the probability to use family planning due to a change in *%users* in a network with $\textit{density} = 1$. A Wald test of the null hypothesis $\delta_1 + \delta_3 = 0$ is rejected at the 1% level for OKW, and for Obisa at the 5% level. (*b*) The linear combination $\delta_2 + \delta_3$ measures the effect on the probability to use family planning due to a change in *density* in a network with $\%\textit{users} = 100\%$. A Wald test of the null hypothesis $\delta_2 + \delta_3 = 0$ is rejected at the 5% level for Obisa in Panel A.

Table 2: Females—fixed effect and random effect logit models for currently using family planning with different specifications of network partners' family planning use. Respondent's contraceptive use is measured at K1, K2 and K3

Method	Fixed Effects Logit	Random Effects Logit	Fixed Effects Logit	Random Effects Logit
At least one family planning user	0.72	0.61	0.69	0.49
in network	(0.30)*	(0.25)*	(0.32)*	(0.26)+
Number of remaining family planning	0.16	0.49	0.07	0.49
users in network	(0.12)	(0.10)**	(0.14)	(0.11)**
At least one non-user			0.01	0.27
in network			(0.30)	(0.24)
Number of remaining non-users			-0.22	-0.19
in network			(0.16)	(0.13)
Dummy for not married, time $t-$	-0.60	-0.64	-0.59	-0.66
	(0.52)	(0.41)	(0.52)	(0.41)
Children ever born, time $t-$	0.10	0.06	0.12	0.06
	(0.12)	(0.05)	(0.12)	(0.05)
Respondent has radio, time $t-$	0.41	0.38	0.39	0.37
	(0.30)	(0.20)+	(0.30)	(0.20)+
Respondent has metal roof, time $t-$	-0.71	0.08	-0.73	0.08
	(0.37)*	(0.22)	(0.37)*	(0.22)
Respondent has at least primary		0.83		0.85
schooling		(0.31)**		(0.31)**
Respondent has secondary schooling		0.61		0.61
		(0.28)*		(0.28)*
Age		0.41		0.41
		(0.11)**		(0.11)**
$(\text{Age}/10)^2$		-0.59		-0.59
		(0.16)**		(0.16)**
Dummy for survey wave Kenya 2	0.35	0.21	0.34	0.21
	(0.24)	(0.22)	(0.24)	(0.21)
Dummy for survey wave Kenya 3	0.60	0.44	0.63	0.45
	(0.29)*	(0.22)*	(0.30)*	(0.23)*
Constant		-11.36		-11.35
		(1.99)**		(1.99)**
N (number of women, each observed at three surveys)	156	497	156	497

Notes: p-values: + $p < 0.1$; * $p < 0.05$; ** $p < 0.01$. Fixed effect logit model is based only on individuals who change their contraceptive behavior at least once between Kenya 1 and Kenya 3; women with constant contraceptive use in all three survey waves are dropped in the estimation We use the subscript "$t-$" to emphasize that the variable refers to the time prior to t, where t refers to the survey wave

Table 3: Females: regression of respondents' risk perceptions on the number of social network partners with high, moderate and low risk perception and personal characteristics ('nwp(s)' = network partner(s))

	Kenya			Malawi		
	GMM FE-IV	Fixed Effect	OLS	GMM FE-IV	Fixed Effect	OLS
# of nwps with high risk perception, time $t-$	0.2199	0.1742	0.1618	0.1036	0.1193	0.1549
	(0.0440)**	(0.0318)**	(0.0237)**	(0.0242)**	(0.0188)**	(0.0131)**
# of nwps with moderate risk perception, time $t-$				-0.1315	-0.0639	-0.0487
				(0.0373)**	(0.0246)**	(0.0184)**
# of nwps with low risk perception, time $t-$	-0.0744	-0.0448	-0.0737	-0.2189	-0.1698	-0.1789
	(0.0429)$^{+}$	(0.0286)	(0.0212)**	(0.0366)**	(0.0229)**	(0.0183)**
children ever born	-0.0907	-0.0111	0.0115	0.0642	0.0003	-0.0055
	(0.0902)	(0.0412)	(0.0146)	(0.0481)	(0.0203)	(0.0082)
dummy for not married, time t	0.1913	0.1725	0.1894	-0.2154	-0.1804	-0.0942
	(0.1903)	(0.1814)	(0.0976)$^{+}$	(0.0966)*	(0.0972)$^{+}$	(0.0543)$^{+}$
Respondent has radio, time t	-0.1456	-0.1164	-0.0881	0.0399	0.0304	0.0278
	(0.1005)	(0.1027)	(0.0632)	(0.0538)	(0.0541)	(0.0343)
Respondent has metal roof, time t	0.0025	-0.0020	0.0430	0.1011	0.0867	0.0295
	(0.1240)	(0.1276)	(0.0670)	(0.0957)	(0.0927)	(0.0587)
AIDS program effort				0.4442	0.4760	0.3989
				(0.1733)*	(0.1750)**	(0.1255)**
Respondent has at least primary education			0.1417			0.0853
			(0.0784)$^{+}$			(0.0368)*
Respondent has secondary education			-0.1180			0.0721
			(0.0876)			(0.0692)
age			0.0216			0.0130
			(0.0274)			(0.0102)
(age/10) squared			-0.0475			-0.0149
			(0.0373)			(0.0129)
Dummy for survey wave Kenya 3 or Malawi 2	0.0363	-0.0190	-0.0206	-0.1073	-0.1114	-0.0964
	(0.0791)	(0.0617)	(0.0528)	(0.0512)*	(0.0374)**	(0.0333)**
Constant			1.9248			1.9322
			(0.4756)**			(0.1774)**
N	545	545	545	1138	1138	1138

Notes: Standard errors in parentheses. *p-values:* $^{+}$ $p \leq 0.10$; * $p \leq 0.05$; ** $p \leq 0.01$.

Table 4: Prevalence of HIV and risk factors for HIV infection across network locations

	Network Location		
	Small components	Main component	Bicomponents
Mean age	27.5	23.4	22.1
(IQR)	(23,32)	(19,27)	(19,25)
Proportion of network members who are			
female	58.9	52.4	46.9[a]
never married	29.1	55.5	63.5[a]
divorced or widowed	10.6	3.9	3.15[a]
Average number of partners			
Males	2.1	2.3	3.8[a]
(Std. Deviation)	(1.6)	(1.2)	(1.4)
Females	1.4	2.2	3.7[a]
(Std. Deviation)	(0.8)	(1.1)	(1.3)
Health variables[b]			
Proportion of respondents who			
were tested for HIV	65.8	72.3	77.0[a]
were infected with HIV	8.9	10.8	3.0
	(5.9,11.8)	(6.3,15.3)	(0.6,5.9)
reported symptoms of STIs	16.7	16.5	17.5
	(13.1,20.4)	(12.1,20.8)	(12.3,22.6)
received an injections within one year prior to survey	34.2 (29.9,38.5)	40.1 (34.4,45.8)	35.0 (29.3,40.7)
were ever tested for HIV prior to this study	21.9 (18.0,25.9)	21.1 (15.9,26.3)	25.3 (19.7,30.8)
Sexual mixing variables[c]			
Proportion of respondents reporting			
any partner outside of Likoma	40.7	25.3	16.9
	(36.5,44.9)	(20.6,30.0)	(14.5,19.3)
any partner above 30 years old	35.8	23.8	12.6
	(32.6,38.9)	(20.0,27.6)	(10.7,14.6)
consistent condom use	16.7	16.7	11.9
	(12.9,20.6)	(11.9,21.5)	(8.8,15.0)
Proportion of relationships that are ongoing at survey among all			
marriages that started more than one year prior to survey	87.2 (83.2,91.2)	93.5 (88.6,98.4)	68.9 (60.2,77.5)
extra-marital relations that started more than one year prior to survey	28.1 (22.0,34.0)	25.6 (20.2,31.0)	21.6 (17.3,26.0)
extra-marital relations that started within one year prior to survey	43.7 (35.1,52.2)	42.7 (34.8,50.6)	40.9 (35.3,46.4)

Network locations: *small components:* members of small components (isolates, dyads, triads, etc.); *main component:* members of the giant component, outside the bicomponents (Figure 4a); *bicomponents* members of the bicomponents within the giant component (individuals connected by thick lines in Figure 4). 95% Confidence intervals are in parentheses unless otherwise noted. [a] The difference in proportions between network locations is significant at the .05 level; [b] Proportions are standardized by age, gender and marital status; [c] Proportions are standardized by age, gender, marital status and number of partners