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Working Paper

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June 1996

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Preface

The research project on *Systems Analysis of Technological and Economic Dynamics* at IIASA is concerned with modeling technological and organisational change; the broader economic developments that are associated with technological change, both as cause and effect; the processes by which economic agents – first of all, business firms – acquire and develop the capabilities to generate, imitate and adopt technological and organisational innovations; and the aggregate dynamics – at the levels of single industries and whole economies – engendered by the interactions among agents which are heterogeneous in their innovative abilities, behavioural rules and expectations. The central purpose is to develop stronger theory and better modeling techniques. However, the basic philosophy is that such theoretical and modeling work is most fruitful when attention is paid to the known empirical details of the phenomena the work aims to address: therefore, a considerable effort is put into a better understanding of the 'stylized facts' concerning corporate organisation routines and strategy; industrial evolution and the 'demography' of firms; patterns of macroeconomic growth and trade.

From a modeling perspective, over the last decade considerable progress has been made on various techniques of dynamic modeling. Some of this work has employed ordinary differential and difference equations, and some of it stochastic equations. A number of efforts have taken advantage of the growing power of simulation techniques. Others have employed more traditional mathematics. As a result of this theoretical work, the toolkit for modeling technological and economic dynamics is significantly richer than it was a decade ago.

During the same period, there have been major advances in the empirical understanding. There are now many more detailed technological histories available. Much more is known about the similarities and differences of technical advance in different fields and industries and there is some understanding of the key variables that lie behind those differences. A number of studies have provided rich information about how industry structure co-evolves with technology. In addition to empirical work at the technology or sector level, the last decade has also seen a great deal of empirical research on productivity growth and measured technical advance at the level of whole economies. A considerable body of empirical research now exists on the facts that seem associated with different rates of productivity growth across the range of nations, with the dynamics of convergence and divergence in the levels and rates of growth of income, with the diverse national institutional arrangements in which technological change is embedded.

As a result of this recent empirical work, the questions that successful theory and useful modeling techniques ought to address now are much more clearly defined. The theoretical work has often been undertaken in appreciation of certain stylized facts that needed to be explained. The list of these 'facts' is indeed very long, ranging from the microeconomic evidence concerning for example dynamic increasing returns in learning activities or the persistence of particular sets of problem-solving routines within business firms; the industry-level evidence on entry, exit and size-distributions – approximately log-normal – all the way to the evidence regarding the time-series properties of major economic aggregates. However, the connection between the theoretical work and the empirical phenomena has so far not been very close. The philosophy of this project is that the chances of developing powerful new theory and useful new analytical techniques can be greatly enhanced by performing the work in an environment where scholars who understand the empirical phenomena provide questions and challenges for the theorists and their work.

In particular, the project is meant to pursue an 'evolutionary' interpretation of technological and economic dynamics modeling, first, the processes by which individual agents and organisations learn, search, adapt; second, the economic analogues of 'natural selection' by which interactive environments – often markets – winnow out a population whose members have different attributes and behavioural traits; and, third, the collective emergence of statistical patterns, regularities and higher-level structures as the aggregate outcomes of the two former processes.

Together with a group of researchers located permanently at IIASA, the project coordinates multiple research efforts undertaken in several institutions around the world, organises workshops and provides a venue of scientific discussion among scholars working on evolutionary modeling, computer simulation and non-linear dynamical systems.

The research focuses upon the following three major areas:

1. Learning Processes and Organisational Competence.
2. Technological and Industrial Dynamics
3. Innovation, Competition and Macrodynamics

Abstract

This paper devises three formal models of 'learning in informal networks' to study the long term implications of word-of-mouth communications for the diffusion of contraceptive knowledge. The models differ in the information that is shared among network partners, and with respect to the sophistication of women's decision rules. The theoretical properties of these models are compared with empirical evidence based on the 1973 Korean survey on women's social networks and contraceptive choices. The analysis proposes a qualitative choice rule that models women's contraceptive decisions as an econometrician's problem to infer the differential quality of contraceptives from informal conversations.

1 Introduction

Learning in informal social networks constitutes an important factor in the dispersion of new ideas and in the promotion of social change. In the analysis of the demographic transition, this process has received particular attention: The diffusion of knowledge about modern contraception contributes to the rapid pace and the high pervasiveness of fertility declines (Cleland, 1987), and it gives rise to persisting geographic, ethnic and cultural differences in demographic practices (Watkins, 1990). An important propagation mechanism for the diffusion of fertility control are *communications* among kin, friends and community members. These conversations are primary channels for the transmission of contraceptive information in many pre-transitional societies, and they often augment knowledge individuals receive from media, official sources or family planning representatives.

A formalization of social learning about fertility control requires an investigation of the idiosyncrasies of communication in informal networks. This paper argues that this formalization needs to include (a) limited exchange of individuals' characteristics during conversations that results in unobserved heterogeneity; (b) communications that focus on technological choices instead of utility levels; and (c) decision rules that combine knowledge obtained through social networks with private information. Although several models of word-of-mouth communication and social learning have recently been developed (Ellison and Fudenberg, 1993 and 1994; Arthur and Lane, 1993; Dosi and Kaniovski, 1994; McFadden and Train, 1995), these characteristics of informal conversations in heterogeneous populations remain largely unaddressed. This analysis shows, however, that these assumptions can significantly change the pervasiveness of information diffusion and the social optimality of long-term outcomes.

This paper motivates the behavioral assumptions underlying the diffusion process with an analysis of word-of-mouth communication about fertility control in rural Korean villages. The following section establishes the empirical regularity that the probability of a randomly selected woman to adopt the pill approximately equals the number of pill-users among her friends. The third section introduces generalized urn process for the dynamic study of learning in informal networks. The forth section proposes a *qualitative choice decision rule* that formalizes contraceptive choice as an econometrician's problem to infer the differential quality of technologies from 'incomplete' communication.[1] This diffusion process is shown to be consistent with the micro-evidence on women's contraceptive choices, and with the macro-observations on contraceptive practices in Korean villages or in pre-transitional European regions. The implication of this qualitative choice model are compared with two alternative specifications. One simplifies the decision rule and neglects private information, and the other assumes 'complete' communications that reveal the actual utility level and the individual characteristics of the network partners.

The conclusions of this analysis extend beyond fertility control. They pertain to the general situation when a person's choice between technologies is influenced by word-of-mouth communication with unobserved heterogeneity. In the demographic context this analysis aids the understanding of fertility declines in developing countries and provides suggestions for the design of family planning programs.

2 Social Learning about Fertility Control

The qualitative aspects of social networking about fertility control have been subject to many sociological and anthropological investigations, and a review of this literature is given for instance in Watkins (1995), Montgomery and Casterline (1994), or Montgomery and Chung (1993). It is evident from these studies that communication with other community members is an important factor in contraceptive decision making. Typically women state that they have learned about contraception by communication with friends, kin or other community members. (Focus group) Interviews with women further show that these conversations among network partners are 'incomplete':[2] The conversations do not reveal many personal characteristics that have determined an individual's choice, and they do not mention the utility level women derive from a specific method. The women exchange primarily information about the type of contraceptive used, possibly along with a subjective evaluation of the method. Attitudes, physiological conditions, and other individual characteristics influencing contraceptive choices are not comprehensively exchanged. Learning about fertility control in informal networks is therefore characterized by unobserved hetero-

[1] For a psychological perspective on the approximation of human decision processes via statistical methods see for instance Ceci and Liker (1986) or Schaller (1984).

[2] Examples for interviews with women, or communications among women about contraception can be found in Watkins, Rutenberg and Green (1995) or in Knodel et al. (1987).

geneity among network partners, and limited information about a method's performance. The women's interpretation of this 'incomplete' information obtained through social networks is primarily an empirical question. Ideally we would like to know the decision rule that determines a women's choice in the presence of social networking. In absence of this knowledge the following analysis provides an empirical conjecture based on the 1973 Korean survey on women's social networks.

Although word-of-mouth communication in traditional societies plays an important role in a woman's choice to adopt modern contraception, an individual's decision is also influenced by socio-economic changes that shape the demand and supply for fertility control (Easterlin and Crimmins, 1985). To emphasize the role of communication and social learning, the empirical investigation in this paper is restricted to women's choice among modern contraceptive methods, conditional on the use of one of these methods. Because these women have chosen to implement effective contraception, this restriction controls (approximately) for the demand and supply factors that influence the decision to practice fertility control.

The 1973 Korean survey includes 1037 married women residing in 25 rural Korean villages with about 30 to 50 women of reproductive age. The survey gives information about the *extent* and information-*content* of social networking about modern fertility control. The former is reflected in the number of neighbors about whose contraceptive use an individual is informed. The latter can be inferred from the distribution of these network partners among available methods.[3] For instance, the larger the proportion of pill users among friends and neighbors, the more information a women learned about the characteristics of the pill, and the less she learned about the features of other methods. The following analysis is based on 268 women in the survey who use modern methods (loop (IUD), pill, condom and vasectomy) and know at least one other community member who uses a modern method.[4] 86 of these women use the pill, 119 the loop (IUD), and 63 rely

[3]The statements about friends' and neighbors' contraceptive methods refer to the 'perceived' use by neighbors. Implicit in this analysis is the assumption that knowledge or perceptions about other women's contraceptive use is derived from previous word-of-mouth communication with these community members. The data do not provide information whether these perceptions about other women's contraceptive use are correct. However, Montgomery (1993) confirms earlier findings that perceptions of community member's use are more important than their actual method of fertility control.

[4]This restriction on the users of modern contraception does not bias the results if the decision to use

on condom or vasectomy for fertility control. The mean age is 21 years, 74% attended at least elementary school, and they have on average 4.2 living children, 0.9 more than their desired fertility level. For simplicity of notation the analysis refers to these 268 users of modern contraception as *umc-women.* Their potential sources of information about fertility control, the users of modern contraception known to the decision maker, are called *umc-friends.*

Table 1 summarizes the average number of contraceptive users among neighbors and friends for all women and for umc-women in the survey. On average, individuals know about seven community members using modern contraception, and women using modern contraception themselves are noticeably better informed about the practice of other community members. More importantly, the method used by a women herself also has the largest representation among her friends and neighbors. This observation is consistent with the hypothesis of information diffusion through word-of-mouth communication when ego's choice is influenced by friends. There are, however, also contrary interpretations in which the knowledge about other community member's contraceptive use does not indicate social networking about fertility control. For instance, this is the case when a women using the pill is more likely to have friends who also use the pill because they meet at the same doctor. Table 1 and the subsequent empirical analysis cannot distinguish these conflicting explanations. Despite this ambiguity in the available survey data, a causal interpretation of table 1 and the following econometric analysis in terms of information diffusion is suggested by other forms of empirical data, such as the qualitative statements of women in focus group interviews.

The following analysis concentrates on the decision to adopt the pill versus other means

modern contraception does not select women with respect to their propensity of using one of the four modern methods. This restriction is in particular consistent with a 2-stage decision process in which women first decide whether to use modern contraception, and in then determine the method in a second step. Formally this assumption reduces to the requirements that a multinomial choice model can be represented in a hierarchical decision tree (for a discussion see McFadden, 1984). The primary reason for not modeling the first stage about the adoption of modern contraceptive is the limited availability of data in the Korean Survey for this estimation, and the 'similarity' of modern methods when they are compared to the alternatives 'traditional methods or no contraception'. The requirement that a umc-woman knows at least one umc-friend drops 46 users of modern contraception that state no knowledge about other community members' contraceptive use. The contraceptive choice of these women therefore cannot be traced with the available data to social networking.

of modern contraception. Very similar conclusions are obtained for the choice of loop versus other modern methods. The analyses of condom and vasectomy are also consistent with the following results, but display a higher variance due to the small number of relevant observations in the survey. In table 2 the women are grouped according to the proportion of pill users among umc-friends. The first column gives the groups with the respective means, and the second and third column give the number of women and the proportion of pill users in each group. The remaining columns give the average number of umc-friends for pill-users and other users of modern contraceptives.

A comparison of columns 1 and 3 in table 2 emphasizes the previous conjecture that a higher proportion of pill users among friends increases the probability of a woman to adopt the pill. Moreover, figure 1 shows a close relationship between the proportion of pill users among network partners, and the proportion of pill users in each of category. In most groups the proportion of pill users among umc-friends approximately equals the proportion of umc-women using the pill. Deviations from this pattern occur primarily in the first and last group where all network partners use an identical method. The claim that this pattern is due to social networking and not village specific effects (such as preferences of local family planning representatives) is supported a regression of the women's contraceptive use on personal characteristics and village dummies. Denote K the number of umc-friends of a women, and m the number of pill users among umc-friends. Let x be a vector of socioeconomic variables, including a constant, the women's age, the number of living children, excess fertility, and education.[5] A logistic regression of the variable 'women uses the pill' on the proportion of pill users among friends $\frac{m}{K}$, the socioeconomic characteristics x and village dummies is reported in the first column of table 3. The estimated parameters show that the proportion of pill-users among friends contributes significantly to the probability of pill-use even when village dummies capture the average pill-prevalence on the village level and other community specific effects.

The clustering of points around the 45 degree line in figure 1 suggests a statistical interpretation that specifies the effect of social networking on contraceptive decisions: the probability of a (randomly selected) woman to choose the pill versus other modern methods

[5]Excess fertility is the difference between a women's number of living children and her stated level of desired fertility. The education variable is an indicator variable that equals one if the women attended at least elementary school.

is approximately equal to the proportion of pill users among her network partners. This conjecture of Pr(umc-woman adopts pill $|X, K, m) = \frac{m}{K}$ is supported in a logistic regression that specifies a woman's contraceptive choice as a function of her socio-economic variables x, the network variables K, m, and other 'non-network' factors, as for instance media. The last factor is expressed as a probability π that a women 'changes her mind' from the choice suggested by her network and socio-economic variables (K, m, x) to the alternative method. The existence of such 'non-network' influences is apparent in the first (last) group of table 2 where women adopt the pill (loop) without knowing any person who uses this method; in these cases the woman's decision cannot be attributed to word of mouth communication.[6] An inspection of columns 4 and 5 in table 2 shows that the women have a distinctly smaller network of umc-friends. This observation suggests that the influence of non-network information decreases with the extent of word-of-mouth communication. Network and non-network influences together then yield the probability of a woman to adopt the pill versus other modern contraceptives in the form[7]

$$\Pr(\text{umc-woman uses pill}|X, K, m) = (1-\pi)p_{nw} + \pi(1-p_{nw}). \qquad (1)$$

$p_{nw} = [1 + e^{\gamma \ln \frac{m}{K-m} + x\beta}]^{-1} \cdot e^{\gamma \ln \frac{m}{K-m} + x\beta}$ is a standard logit formulation for the probability that a woman adopts the pill based on (x, K, m). The probability p_{nw} reduces to the conjectured relation $p_{nw} = \frac{m}{K}$ if $(\gamma, \beta) = (1, 0)$. The probability π that 'non-network' information leads to a 'change of mind' is specified as $\pi = e^{\alpha_0 + \alpha_1 K}$. The maximum likelihood estimation results for equation 1 are given in the second column of table 3. They indicate that the socio-economic characteristics of women do not significantly influence the contraceptive choice among modern methods once the social network is included. Furthermore, a Wald test for the null-hypothesis that $(\gamma, \beta) = (1, 0)$ yields a χ^2_6 distributed test statistic of 1.044 ($p = 0.984$). The parameter restriction is not rejected, and hence the conjecture that $p_{nw} = \frac{m}{K}$ is supported by the Korean data. The coefficients for π indicate that the influence of non-network information is relatively weak. The average number of umc-friends for women in this sample is slightly more than 10 and hence the probability that a woman 'changes her mind' on the basis of non-network information is

[6] Of course, there may be 'second-hand' information that is transmitted through social networks. In the absence of any data to investigate this aspect these decisions that 'contradict' the composition of a woman's social network are attributed to non-network information.

[7] This model is a modification of the error in binary response model discussed in Cox and Snell (1989).

0.06; this probability increases to 0.20 for women with only three umc-friends and explains the observed adoption of pill (loop) even in absence of umc-friends using the this method.

The analysis indicates that women evaluate network-information in combination with their private knowledge about personal characteristics. The more popular the pill is among her friends, the more effective the pill is perceived by the decision maker, and the more likely she will adopt the pill. If women ignored their private information, they would follow the majority of their friends in order to choose the optimal contraceptive method. This behavior is not consistent with empirical observation that suggests a pattern in the form $p_{nw} = \frac{m}{K}$. The gradual increase in a woman's probability to adopt the pill as the proportion of pill-users among her friends increases suggests a decision rule that evaluates the information obtained from other women with private knowledge such as preferences, religious attitudes or medical reason.

The next section introduces generalized urn processes to study the implications of social learning for the diffusion of contraceptive practices over time. The analysis then derives a decision rule that motivates and rationalizes above empirical observations. The following discussion is framed in terms of a woman's choice between a modern method and a traditional method of contraception. It should be understood that the terms 'modern' and 'traditional' can be replaced by any other contraceptive or technological alternatives, as long as the importance of word-of-mouth communication on individuals' choices is maintained.

3 A Simple Model of Diffusion

Imagine that there are two possible contraceptives, a modern method M, and a traditional method T. Women choose the contraceptive that offers the higher utility. The population is assumed to be homogeneous with respect to observable characteristics, but there is an individual-specific deviation from the average that is know to the women but not generally observable. Moreover, the woman's knowledge about her individual characteristics is imperfect, and hence there is an unanticipated 'surprise' component that the woman learns only after adopting one of the two methods.

The woman's utility from using a contraceptive method is given by

$$U_i = \mu_i + \epsilon_i + \nu_i, \quad i = M, T.$$

This utility is decomposed into the average utility μ_i, the individual specific component known to the woman ϵ_i, and the unanticipated random effect ν_i. Assume that (ϵ_M, ϵ_T) has a joint normal distribution with mean zero and covariance matrix Σ. Let ν_i, $i = M, T$ be i.i.d. normal[8] with mean zero, variance $\frac{1}{2}\sigma^2$ and independent of (ϵ_M, ϵ_T). Since the woman's decision depends only on the difference in utility levels we can write

$$\begin{aligned} \Delta U &= \mu_M - \mu_T + \epsilon_M - \epsilon_T + \nu_M - \nu_T \\ &\equiv \mu + \epsilon + \nu, \qquad (2) \\ &\quad \text{where } \mu = \mu_M - \mu_T,\ \epsilon = \epsilon_M - \epsilon_T \text{ and } \nu = \nu_M - \nu_T. \end{aligned}$$

The parameter μ expresses the average utility difference women derive from M and T. It can also be interpreted as the (average) differential effectiveness of the two methods. ϵ reflects women's religious, attitudinal or physiological differences with respect to contraceptive use. Without loss of generality we can specify $\epsilon \sim N(0,1)$. Since ν is unknown to the decision maker, a woman chooses M if $\mathrm{E}[\Delta U \mid \epsilon] = \mu + \epsilon \geq 0$ and T otherwise.

In traditional societies it is reasonable to assume that women do not use contraception early in their marriages. The incentive to implement contraceptive techniques arises once a women achieves her desired family size (see for instance Easterlin and Crimmins, 1985). She then chooses between two available techniques: the traditional method T, or the modern method M, both of which are available at zero monetary costs.[9] The utility of these methods differs from person to person. These differences are reflected in the average utility difference μ, and the individual specific utility difference $\epsilon+\nu$ in equation 2. Women are aware of their individual characteristics ϵ, but neither know the surprise component ν nor recognize the individual characteristics of their network partners.

If μ is publicly known, a randomly selected woman reaching her desired family size chooses contraceptive M with probability $\Pr(\mu + \epsilon \geq 0) = \Phi(\mu)$. Because ν is i.i.d. across individuals and ϵ is a known individual-specific deviation there is no incentive for

[8] The normality assumptions for ϵ_i, ν_i, $i = M, T$ are strictly for convenience of notation and innocuous for the results of this paper. All the results can be established with any other mean zero, well behaved distribution.

[9] The zero monetary cost assumption eliminates the need to consider budget considerations. A extension to include small cost differentials follows naturally by introducing a decision threshold that is different from zero in the choice rule 'choose M if $\mathrm{E}[\Delta U \mid \epsilon] = \mu + \epsilon \geq 0$ and T otherwise'. Significant monetary costs require the explicit modeling of the budget constraint and are not pursued here.

a woman to gather additional information. In the long term the proportion of M-users in the contracepting population converges to $\Phi(\mu)$. Because a priori the individuals' decisions cannot be improved unless we impose knowledge of ν, this convergence for the proportion of M-users to $\Phi(\mu)$ is the optimal or *socially efficient* outcome.

The more interesting case pertains to the situation when women do not know the differential effectiveness μ of the available methods M and T. Because there is no public information about fertility control, women base contraceptive decisions only on their private information ϵ, in combination with the advice obtained from other community members. We assume that the informal interactions among community members take the form of random sampling: the decision maker randomly selects K current contraceptive users (i.e., women using either M or T), and asks them about their method of fertility control. Based on these responses and her private knowledge she decides on one of the two alternatives. After making her choice for either method M or T, the woman adds herself to the contracepting population and becomes a potential information source for future decision makers.

This analysis devises three behavioral rules that determine the contraceptive choice given a specific sample outcome. These rules differ in two dimensions: (a) in information content of conversations among network members, and (b) in the sophistication of individuals' decision rules. All of the following models assume a heterogeneous population as specified in equation 2. Initially the paper considers models in which communication does not completely reveal the heterogeneity among network partners. The first decision rule is a *majority model* in which women will adopt the most popular choice in their samples with probability α, and opt for the minority response with probability $1 - \alpha$. In the following *qualitative choice models* women make statistical inferences from their samples, and decide based on the estimated differential effectiveness of the two methods. In this decision rule, women optimally utilize private knowledge and the 'limited' information learnt from other community members. The final analysis contrasts the implications of the previous models, that are based on 'limited' communication among network partners, with a *revealed utility model* that assumes 'complete' communications about utility levels and individual characteristics.

The unifying formal framework for these diffusion models is a generalized Polya urn scheme. 'Time' is measured in number of women reaching their desired family size and making contraceptive decisions. The following notation and structure is common to all parts of the analysis. Denote

- X_n: proportion of women in the contracepting population using method M at time n.
- $1 - X_n$: proportion of women in the contracepting population using method T at time n.
- B_n: random variable that equals one if $n + 1^{st}$ woman adopts contraceptive M, and equals zero otherwise.
- $p(K, m, \epsilon)$: probability that a woman with individual-specific characteristic ϵ chooses M, given a sample of size K containing m users of contraceptive M.
- $p(K, m)$: probability that a *randomly* selected woman chooses M, given a sample of size K containing m users of contraceptive M; note $p(K, m) = \mathrm{E}[p(K, m, \epsilon)]$.

The function $p(K, m, \epsilon)$ captures the woman's decision process: it gives the conditional probability of choosing contraceptive M, given her individual characteristic ϵ and a sample of size K containing m users of method M. Assume that there are initially γ_0 contraceptive users, and that women reach their desired family size randomly with respect to ϵ. When the $n+1^{st}$ woman engages in word-of-mouth communication she samples without replacement from a pool of $\gamma_n = \gamma_0 + n$ contracepting woman of whom $X_n = x_n$ are using method M. The probability that the $n + 1^{st}$ woman will chose M, given $X_n = x_n$, is given by

$$\begin{aligned} q_n(x_n) &= \Pr(B_{n+1} = 1 \mid X_n = x_n) \\ &= \sum_{i=0}^{K} \frac{\binom{x_n\gamma_n}{i}\binom{\gamma_n - x_n\gamma_n}{K-i}}{\binom{\gamma_n}{K}} p(K, i). \end{aligned} \tag{3}$$

The last term in equation 3 specifies the probability that a randomly selected woman chooses M, given that her social networking yields a sample of K informants containing i users of the modern method. Taking expectations with respect to all possible sample outcomes gives the probability of a randomly chosen women to adopt method M. The hypergeometric distribution in above expression can be written as

$$\begin{pmatrix} K \\ i \end{pmatrix} \frac{x_n(x_n-\frac{1}{\gamma_n})\cdots(x_n-\frac{i-1}{\gamma_n})(1-x_n)(1-x_n-\frac{1}{\gamma_n})\cdots(1-x_n-\frac{K-i-1}{\gamma_n})}{1(1-\frac{1}{\gamma_n})\cdots(1-\frac{K-1}{\gamma_n})}$$

$$= \begin{pmatrix} K \\ i \end{pmatrix} x_n^i(1-x_n)^{K-i} + \delta_{XK}(\gamma_n, x_n),$$

where $\delta_{XK}(\gamma_n, x_n) \leq \frac{c_{XK}}{n}$ $\forall x_n \in [0,1]$ and some constant c_{XK}. Because $p(K,m)$ is bounded and independent of n equation 3 simplifies to

$$\begin{aligned} q_n(x_n) &= \sum_{i=0}^{K} \begin{pmatrix} K \\ i \end{pmatrix} x_n^i(1-x_n)^{K-i}p(K,i) + \delta_K(\gamma_n, x_n) \\ &\equiv q(x_n) + \delta_K(\gamma_n, x_n), \qquad (4) \\ & \quad \text{with } \sup_{x\in[0,1]} \delta_K(\gamma_n, x) \leq \tfrac{c_K}{n} \text{ for some constant } c_K, \\ & \quad \text{and } q(x) = \textstyle\sum_{i=0}^{K} \begin{pmatrix} K \\ i \end{pmatrix} x^i(1-x)^{K-i}p(K,i). \qquad (5) \end{aligned}$$

The dynamics of contraceptive prevalence in the population are determined by the evolution of X_n, the proportion of contracepting woman using method M. Let the process begin with initially γ_0 contraceptive users of whom a proportion X_0 employs method M. Recursive calculation of X_n yields following stochastic process:

$$\begin{aligned} X_{n+1} &= \left(1 - \frac{1}{\gamma_0 + n}\right) X_n + \frac{1}{\gamma_0 + n} B_{n+1} \\ &= X_n + \frac{1}{\gamma_0 + n}(X_n - q_n(X_n)) + \frac{1}{\gamma_0 + n}(B_{n+1} - q_n(X_n)). \qquad (6) \end{aligned}$$

The process $\{X_n\}$ is a generalized urn scheme studied in Arthur et al. (1986), Hill et al. (1980) and Dosi et al. (1994). Because $q_n(x)$ converges to $q(x)$ at a rate faster than n, it follows from theorem 3.1 in Arthur et al. (1987) that X_n itself converges almost surely on the set of fix points of the urn function $q(x)$. For the one-dimensional case where X_n is a random variable denote a fix point x^* an upcrossing if $q(x^*) > 1$, and call x^* a downcrossing if $q(x^*) < 1$. The possible limits for X_n are the intersections of $q(x)$ with the

45 degree line. Moreover, theorem 6.3 in Arthur et al. rules out upcrossings as possible limits.

The analysis of information diffusion on the basis of generalized urn schemes starts with a specification of the decision rules that determine $p(K, m, \epsilon)$, the probability that a woman with individual characteristic ϵ chooses method M on the basis of social networking with K contraceptive users, of whom m implement method M. On the basis of this decision rule the urn function $q(x)$ is calculated by $p(K, m) = \mathrm{E}p(K, m, \epsilon)$ and inserting into equation 5. The dynamic implications of word-of-mouth communication on the contraceptive prevalence follow because asymptotically the proportion of M users in the contracepting population, X_n, will converge to one of the fix points $\{x \mid q(x) = x\}$. Although this is a limiting argument on the basis that $n \to \infty$, finite time distributions for X_n can be obtained by recursively evaluating the urn function $q_n(x)$. The examples given later show that the process converges relatively fast, and that after 60-80 contraceptive decisions the contraceptive prevalence X_n is already well described by the limiting behavior.

The simplest decision rule for contraceptive choice on the basis of word-of-mouth communication is a majority rule that ignores the individual-specific information ϵ: a woman makes her contraceptive choice only dependent on the behavior of the majority in her sample. In particular, we specify that a woman adopts the method of the majority with probability α, and chooses the alternative method with probability $1 - \alpha$. To rule out ties we let the sample size K be odd. From this majority based decision rule, we can now write

$$p(K, m, \epsilon) = p(K, m) = \begin{cases} \alpha & \text{if } m \geq (K+1)/2 \\ 1 - \alpha & \text{if } m < (K+1)/2 \end{cases}$$

Inserting this expression in equation 4 yields after some algebra

$$\begin{aligned} q(x) &= \Pr(B_{n+1} = 1 \mid X_n = x_n) = 1 - \alpha + (2\alpha - 1)b(K, x), \qquad (7) \\ & \text{where } b(K, x) = \sum_{i=(K+1)/2}^{K} \binom{K}{i} x_n^i (1 - x_n)^{K-i}. \end{aligned}$$

Let $\beta(K, x) = \frac{\partial}{\partial x} b(K, x)$. Depending on the parameters α and K we can distinguish the following cases, that are depicted in figure 2: (a) $K \geq 1, \alpha = 0.5$: $q(x) = 0.5 \,\forall x$ and has single downcrossing at $x = 0.5$; (b) $K = 1, 0 \leq \alpha < 1$: $q(x)$ is a straight line with slope $(2\alpha - 1)$ and has a single downcrossing at $x = 0.5$; (c) $K = 1, \alpha = 1$: $q(x) = x$, and all $x \in [0,1]$ are possible limit points; (d) $K = 1, \alpha = 0$: $q(x) = 1 - x$, and has a single downcrossing at $x = 0.5$; (e) $K > 1, \alpha < \beta(K, 0.5)$: $q(x)$ has a single downcrossing at $x = 0.5$; (f) $K > 1, \alpha > \beta(K, 0.5)$: $q(x)$ has 3 fixed points: one downcrossing at $x = 0.5$, and two upcrossings at $x_0(\alpha)$ and $x_1(\alpha)$ (note: for $\alpha = 1 : x_0(1) = 0$ and $x_1(1) = 1$).

In cases (a), (b), (d), and (e) the proportion of M-users in the population will eventually converge to 0.5, independent of the of the actual utility obtained with the methods M or T. In all these cases, α is relatively small, and hence the influence of the majority's choice is not strong enough to induce increasing returns into the decision making process. The evolution of the X_n is not path dependent, and the initial proportion of M-users has no impact on the limiting distribution.

If women are uncertain about the contraceptive effectiveness, it is plausible that decision makers tend to follow the majority with a high probability. The information diffusion process with α close to one equals case (f) above, and $q(x)$ has three fixed points as shown in figure 2. The downcrossing is not attained as a possible limit of X_n, and we conclude that one of the two methods M or T will eventually dominate in the contracepting population. Independent of the initial proportion of M-users both outcomes have a positive probability. This model exhibits a 'snowball-effect' due to information diffusion: If initial choices increase the proportion of M-users, subsequent decision maker have a higher probability of finding a majority of M-users in their samples. Hence, they tend to follow the initial adopter's choice, and in the long term only one method will prevail in the contracepting population.

This convergence towards the dominance of one method is relatively fast. Assume for instance the following example: A family planning representative contacts 10 women in a village and informs them objectively about the two methods of fertility control. The women learn in this conversation that the (average) differential effectiveness between the two methods is $\mu = 0.253$. Suppose exactly the expected number $10 \cdot \Phi(0.253) = 6$ choose method M.[10] In above formal framework this implies that $\gamma_0 = 10$ and $X_0 = 0.6$. If further contraceptive use in this village is determined by word-of-mouth communication

[10]This outcome is motivated by the idea that the FP representative cannot select women with respect to the unobservable characteristic ϵ, and he can also not coerce women to use M if it were not the optimal choice with $\mu + \epsilon \geq 0$.

with a majority rule ($\alpha = 1$), one of the two methods will become a dominant method of fertility control. The first two columns of table 4 indicate the speed of this convergence: already after 40 women have made their contraceptive choices, the probability that method T or M is used by more than 80% is 0.015 and 0.89 respectively.

The primary theoretical criticism against this majority model is the lack of microeconomic foundations in the decision rules. It is not at all clear why persons in a heterogeneous population ought to follow the majorities choice with a pre-determined probability α. The primary empirical criticism refers to the model's inconsistency with observed demographic patterns: The majority rule is not consistent with figure 1, indicating a linear increase in the probability to adopt the pill as the proportion of pill users among friends rises. Moreover, the model does not predict the variety of demographic patterns observed by Watkins' (1990) in pre-transitional Europe, or the non-uniformity of pill use in the Korean villages shown in figure 3: in all cases with $K > 1$ above model predicts either convergence between regions, or a polarization between two possible outcomes.

4 Qualitative Response Models

A modification of the individuals' decision rules reconciles the dynamics of the diffusion process with the empirical observation in pre-transitional Europe and Korea. This section establishes explicit micro-foundations for contraceptive decisions based on social networking, and increases the information women *infer* from their respective samples. Contraceptive choice in this model is motivated by rational behavior when word-of-mouth communication is characterized by limited information transmission and unobserved heterogeneity. Individuals 'optimally' interpret the partial information they learn through conversations with other community members, and form contraceptive choices by combining private information with the advice of friends and neighbors.

In particular, this section restricts conversations among women to current contraceptive use and a limited amount of socio-economic information. The model then assumes that women approach the problem of contraceptive choice like an econometrician, who tries to infer the true parameters from a sample population. The econometrician's sample corresponds to the information obtained by social networking, and the estimation problem corresponds to the inference of μ, the differential effectiveness of methods M and T.

The woman's contraceptive choice is based on the estimated parameter $\hat{\mu}$ and her private information ϵ. Of course, this analysis does not imply that women actually form and maximize likelihood equations when making contraceptive decisions. However, this section argues that the empirical patterns in the Korean data, and the variation of contraceptive prevalence in communities can be understood and rationalized on the basis of this decision model.

The first subsection focuses on a situation with no observable heterogeneity among individuals. Women's contraceptive decisions depend only on private information, such as personal preferences and attitudes, and on the number of M and T users among friends and neighbors. The subsequent subsection confirms that the main conclusions also hold with observable differences in the population, such as religion or race.

4.1 No observable heterogeneity in the population

When women base their contraceptive decision on word-of-mouth communication they assume that the answers reflect the true differential effectiveness μ of the methods: They expect the objectively superior method to dominate in their respective social networks. Since a person only interacts with a randomly selected subset of the population, women believe that the data-generating process underlying the sample is given by equation 2 combined with the decision rule 'choose M if $\mathrm{E}[\Delta U \mid \epsilon] = \mu + \epsilon \geq 0$ and T otherwise'. If they were not convinced of this fact, asking other community members about their contraceptive *choices* would not be a sensible procedure to gather information about μ. It is important to understand that these beliefs are not objectively true in a process of sequential decisions. Because each decision maker samples previous users and adds herself to the pool of users after her decision, the contracepting population becomes 'contaminated' with women who made wrong decisions due to sampling variation. The effect of these wrong decisions prevails because they change the distribution of future sampling outcomes. At any time n the proportion of M-users does not necessarily reflect the true data-generating process with parameter μ, but results from path-dependent sequential decisions. The analysis in this section assumes that individuals are only boundedly rational: they are not aware of this implication of sequential decisions. Given these beliefs, a decision rule that replicates the estimation of a qualitative choice model is the optimal behavior of women because they infer the maximal information from any given sample.

The specification of utility in equation 2 implies that a woman who knows her individual ϵ will choose M if $\mathrm{E}[\Delta U \mid \epsilon] = \mu + \epsilon \geq 0$. If μ is unknown the decision maker replaces μ by an estimate $\hat{\mu}$ inferred from word-of-mouth communication. The estimation of $\hat{\mu}$ from a sample of binary variables indicating the contraceptive use of network partners is a standard application of qualitative choice models. Given a sample of size K with m respondents using methods M, $\hat{\mu}$ is the maximizer of the log-likelihood function

$$L(\mu; K, m) = m \log \Phi(\mu) + (K - m) \log \Phi(-\mu).$$

In this simple case with no observable heterogeneity, $\hat{\mu} = \Phi^{-1}(\frac{m}{K})$, where Φ^{-1} is the inverse of the cumulative normal distribution function.[11] The woman chooses method M if $\hat{\mu} + \epsilon \geq 0$, and method T otherwise.

The dynamics of the X_n, the prevalence of modern contraception, follow from equation 6 after the probability $p(K, m)$ that a randomly selected woman will choose M, given a sample of size K with m respondents using method M, is established. Observe

$$p(K, m) = \Pr(\hat{\mu} + \epsilon \geq 0 \mid K, m) = \Phi(\hat{\mu}) = \frac{m}{K}. \tag{8}$$

That is, the probability of the $n + 1^{st}$ woman choosing method M equals the proportion of M-users she observes in her sample drawn from the $\gamma_0 + n$ women currently using method M or T. Intuitively, in binary qualitative choice models the average predicted probability of using M has to equal the proportion of M-users in the sample. With no observable heterogeneity this reduces to the requirement that $\hat{\mu}$ predicts the observed sample frequency.

The theoretical finding of equation 8 is consistent with the empirical observation in figure 1: It implies that the probability of a (randomly selected) woman to choose method

[11] Notes: (a) This property holds for simple qualitative choice models and is independent of the normality assumption which is used primarily for analytic convenience. It is easily derived by taking the first order conditions of the likelihood function. This argument requires, however, that women know the distribution of ϵ, or the 'amount of heterogeneity' in the population. This assumption is supported by psychological surveys that indicate individuals' knowledge about the distribution of certain traits in a population; see for instance Holland et al. (1986) for a discussion. (b) This qualitative choice model is not defined if the sample contains only users of a single method. This indeterminacy is resolved by assuming that a woman decides for the only method that is contained in her sample. That is, if a sample of size 5 revealed only T-users, the woman will also choose T independent of her ϵ.

M equals the proportion of M-users in her sample. It therefore predicts the observation of table 2 that in each group the proportion of pill users among umc-women equals the average proportion of pill-users among umc-friends. This finding also shows that an increase in the network size, holding $\frac{m}{K}$ constant, has no effect on the probability to adopt M.

Given expression 8 we can calculate the urn function $q(x)$ for the qualitative choice model:[12]

$$q(x) = \sum_{i=0}^{K} \binom{K}{i} x^i (1-x)^{K-i} \frac{i}{K} = x. \tag{9}$$

This urn function $q(x)$ equals the 45 degree line, and hence all points on $[0,1]$ are fix points and possible limit points for the generalized urn process X_n. Equation 9 reveals the main insight of this section: Assume women have the boundedly rational beliefs mentioned at the beginning of this section, and sequentially sample the pool of M and T users by word-of-mouth communication. If they make their contraceptive decisions according to above qualitative choice rule, the proportion of M-users in the contracepting population converges to a fixed proportion X, and the distribution of this limiting proportion X has continuous support on $[0,1]$.

The continuation of above numerical example makes this finding clearer. Assume again that a family planning representative has consulted 10 women in a village about fertility control, and that for $\mu = 0.253$ the expected number 6 have adopted method M. Word-of-mouth communication with qualitative choice decision rules determines the contraceptive choices for the all other women in the community. Figure 4 shows the probability distribution for X_n after 10 to 200 women have made contraceptive choices.

The distribution starts with a peak at the initial value. Then the distribution of X_n becomes more dispersed, indicating the uncertain effects of word-of-communication on the diffusion of contraceptive knowledge. Depending on the decisions of the first adopters, social learning may either increase the prevalence of method M, or result in a larger usage of the traditional method T. Yet, a dominance by method M or T is relatively unlikely. Table 4 shows that after 80 women have made contraceptive decisions, the probability of method T or M being used by more than 80% of the contracepting population is only 0.0015 and 0.064 respectively. In contrast to the majority rule, the distribution of X_n

[12] To see why the second equality below holds, multiply both sides by K and observe that the resulting relation is the mean of a binomial distribution.

approaches a bell-shaped form with considerable variation. This qualitative choice model implies a long-term coexistence of both methods within the same village, and it predicts a regional diversity of contraceptive practices among villages.

A slight simplification allows us to establish the limiting distribution of X_n analytically. So far the analysis has assumed that the sampling of community members is without replacement, yielding the hypergeometric distribution in equation 3. If the initial number of contraceptive users γ_0 is large compared to the sample size K, then the difference between sampling without replacement and with replacement is minor.[13] If the sampling in word-of-mouth communication is with replacement, the term $\delta_K(\gamma_n, x_n)$ in equation 4 disappears, the urn function reduces to $q_n(x) = q(x) = x$, and X_n follows a Polya urn process.[14] This holds independent of the size K of social networks. The random limit X of the proportion of M-users in the contracepting population has a beta distribution depending *only* on the initial number of contraceptive users γ_0, and the initial proportion of M-users, X_0. In above example with $\gamma_0 = 10$ and $X_0 = 0.6$ the limiting density function for X_n is given in figure 5. Despite the fact that the initial composition reflected the 'socially optimal' outcome under knowledge of μ, the limit of the information diffusion process can deviate significantly. The 25% and 75% percentiles of the distribution in figure 5 are 0.55 and 0.71 respectively. The degree of deviation does not depend on the effort that women put into gathering information: the limiting distribution is independent of the network size K. In particular this limiting distribution is also achieved if the sample size K is a random variable; a sufficient condition for this assertion to hold is independence of K from the individual characteristic ϵ. That is, if a woman's effort to gather information is random, but independent of her private information, the beta-distribution continues to characterize the long-term consequences of word-of-mouth communication.

These properties are consistent with Watkins' observation of regional diversity in demographic practices in pre-transitional Europe, or in rural Korea. In above diffusion model, regions starting with an identical (not too large) 'base' of contraceptive users can converge to a variety of different outcomes; there is no polarization as in the case of the majority rule. The Korean pattern exhibited in figure 3 with a wide variety of demo-

[13] A common rule of thumb for the approximation of the hypergeometric distribution by the binomial distribution is $20 \cdot K \leq \gamma_0$.

[14] See for instance Feller (1971) for a proof of this proposition.

graphic practices prevailing in separated village populations is typical for the information diffusion process in this section.

This analysis further indicates that information diffusion through 'limited' communication among community members is a relatively inefficient way of learning, even though women optimally infer the information contained in their samples. This argument also suggests that a family planning program should not focus on improving the diffusion channels, i.e., increasing the sample size to which each woman uses in her decision process. Instead it has to focus in establishing a large initial base of M-users which are the basis for subsequent samples. Figure 5 also shows the beta limiting-distribution for $\gamma_0 = 100$ instead of 10 in the previous example. In this case the limiting distribution is much more concentrated around the optimal outcome of 0.6. To assure that information diffusion leads to an outcome that is close to this optimal value, the family planning program has to establish a large base initial users.

4.2 Observable heterogeneity in the population

This section verifies that the conclusion established above holds even if there is observable heterogeneity within the population. We assume that the population is divided into two groups $j = 0, 1$ according to some observable characteristic z, say religion. The utility of the contraceptive methods M and T differs for the members of this subgroups. A randomly selected women belongs to group zero with probability $1 - y$, and to group one with probability y. Hence, z is a random variable taking zero for members of group 0, and one for members of group 1. Maintaining all relevant assumptions of the previous section we can write

$$\Delta U = \mu + \beta z + \epsilon + \nu. \tag{10}$$

If we assume that there is no communications across the two groups and each woman samples only members of her own group, then the contraceptive prevalence in each group evolves independently according to the previous analysis. The interesting case therefore concerns the situation when women observe the choices of members in both groups and also know to which group each member of the sample belongs. For simplicity we suppose that sampling is random across both groups (for instance, a woman learns about the characteristic only during the conversation and does not know it a priori). A woman deciding about fertility control draws a sample of size K from the contracepting population with the following composition: K_j members of the sample belong to group j, and m_j respondents of group K_j are using method M. She then chooses μ and β to maximize the likelihood function[15]

$$\begin{aligned} L(\mu,\beta,K,m) &= m_0 \log\Phi(\mu) + (K_0 - m_0)\log\Phi(-\mu) + \\ &\quad m_1 \log\Phi(\mu+\beta) + (K_1 - m_1)\log\Phi(-\mu-\beta). \end{aligned}$$

The dynamics of contraceptive prevalence in each of the four groups can be modeled with a 4-color urn reflecting each of the four possible combinations between contraceptive M or T, and group 0 or 1. Yet, since the distribution of women between the groups $j = 0, 1$ is exogenously given, the long-term properties of $X_{n,j}$, $j = 0, 1$ can be established using the familiar one-dimensional process. Denote y_n the proportion of group j in the contracepting population, and let $X_{n,j}$ be the proportion of the contracepting population belonging to group j, $j = 1, 2$ who uses contraceptive M at time n. Furthermore use $p(K_0, K_1, m_0, m_1, z)$ for the probability that a randomly chosen woman belonging to group z will adopt M, given that a sample of size $K_1 + K_2$ contains m_j users of contraceptive M belonging to group j, $j = 0, 1$. Similar to the previous analysis we enumerate all possible sample compositions, and calculate the probability that a randomly selected woman of group j chooses method M based on each sample composition. Taking first order conditions for the likelihood function yields that $\hat{\mu} = \Phi^{-1}(\frac{m_0}{K_0})$, and $\hat{\beta} = \Phi^{-1}(\frac{m_1}{K_1})$. The probability of a randomly selected woman of group j to adopt M, given the outcome of word-of-mouth communication, then follows as

$$p(K_0, K_1, m_0, m_1, z = j) = \frac{m_j}{K_j},$$

which is similar to the previous section: The probability of a randomly selected group-j-woman to choose M equals the proportion of M users among the group-j-women in her sample. From the large law of numbers it follows that $y_n \to y$. Some more algebra reveals that the probability of a randomly selected women of group one choosing method M is

[15] Again, the parameters in the likelihood function are not defined if the sample does not contain at least one member of each of the four possible combinations between contraceptive and group. This indeterminacy is resolved by assuming that a woman chooses method M (or T) in these cases with probability equal the proportion of M (or T) users in the sample belonging to her group.

given by

$$\begin{aligned}
&\Pr(\text{ randomly selected woman of group } j \\
&\quad \text{will adopt method } M \mid x_{n,0}, x_{n,1}, y_n) \\
&= \sum_{k=1}^{K} \binom{K}{k} y_n^k (1-y_n)^{K-k} \sum_{i=0}^{k} \binom{k}{i} x_1^i (1-x_1)^{k-i} \frac{i}{k} \\
&= x_1 .
\end{aligned}$$

An equivalent relation holds for members of group zero. The first part of above equation gives the probability of finding k women of one's own group in a sample of size K. The remainder of above equation decomposes k into M and T users and multiplies each sample outcome with the predicted probability of adopting M. We see from this expression that the probability of a randomly selected woman of group j adopting M only depends on the proportion of M-users in her own group. This implies that the contraceptive prevalence in each group evolves independently, although the each woman randomly samples from both groups. This property arises because women tend to attribute group differences in the sample composition to the observed characteristics rather than to the differential effectiveness μ of the methods. The respective asymptotic properties derived in the previous section hold for each of the groups individually, and the two limiting shares are independent of each other.

Two main conclusions can be drawn from above argument: First, if groups differ in observable characteristics then above information diffusion process does not induce correlation in the contraceptive prevalence, even if network partners are randomly drawn from both groups. This model is consistent with regional diversity in contraceptive practices, and with variation of demographic behavior across different social strata even in the presence of communication across social barriers. Second, for a family planning program that relies on diffusion of knowledge for the long term prevalence of a contraceptive M it is crucial that the initial contracepting population contains M-users in both groups. It is not sufficient to convince members of one religious group of a modern contraceptive and hope that by diffusion the other religious group will adopt the method as well. Above argument shows that this is not the case if religion is an observable characteristic and people anticipate that this characteristic has an effect on the adoption of a contraceptive method.

5 A Revealed Utility Model

The previous sections assumed that informal conversations among community members are incomplete: word-of-mouth communication does not inform about the exact utility level of other contraceptive users, and it does not reveal completely the heterogeneity in the population. The 1973 Korean survey indicates that the women's decision process in this situation is approximately replicated by a qualitative choice model in which women optimally infer the differential effectiveness of the contraceptive methods from the limited sample information.

For the completeness of the analysis this final section investigates a revealed utility model as alternative assumption on women's interactions. The model in this section supposes that the diffusion of contraceptive knowledge is based on an *intensive* communication of community members. Recall that the utility a woman achieves using method i is given by $U_i = \mu_i + \epsilon_i + \nu_i$, $i = M, T$. Intensively interacting women exchange not only their contraceptive choices, but also the experienced utility and all relevant private information. The conversation among network partners hence reveals the implemented method $i = M, T$, the utility level U_i, and the individual characteristics ϵ of all network partners. Since ν_i, $i = M, T$ are i.i.d., the conversation with one neighbor specifies a 'noisy' observation $\hat{\mu}_i$ of the mean effectiveness μ_i for the method i used by this neighbor. In particular, $\hat{\mu}_i \sim N(\mu_i, \frac{1}{2}\sigma^2)$ where $\frac{1}{2}\sigma^2 = \mathrm{var}(\nu_i)$. From a sample of size K containing m users of method M a woman can calculate the sample means of $\hat{\mu}_i$ for $i = M, T$. Let $\bar{\mu}_i$ denote these sample means. A woman then chooses M if the expected utility of using M exceeds the excepted utility of using T, that is, if $\bar{\mu}_M - \bar{\mu}_T + \epsilon \geq 0$. The probability of a randomly selected woman choosing M based on this sample is

$$p(K, m) = \Pr(\bar{\mu}_M - \bar{\mu}_T + \epsilon \geq 0 \mid K, m) = \Phi\left(\frac{\mu}{\sqrt{1 + \frac{\sigma^2}{2}(\frac{1}{m} + \frac{1}{K-m})}}\right). \quad (11)$$

A sample containing only users of one method does not reveal any information about the relative effectiveness; however, it is reasonable to assume that in this case a woman adopts the method contained in her sample. This assumption together equations 11 and 3 specifies the urn function for the dynamic analysis of the revealed preference model.

In the long term the proportion of M users in the contracepting population X_n will converge to the set of fixed points of the urn function $q(x)$. Figure 6 shows the urn function for the earlier example with $\mu = 0.253$ and $\sigma^2 = 1$. These parameters imply a 'socially optimal' outcome for X_n of 0.6. If the sample size is large enough, women obtain very close estimates of the true μ_i by asking acquaintances. It is therefore not surprising that the only possible limit point of $q(x)$ for large K is a single downcrossing close to the optimal outcome of 0.6. For small K additional possible limit points at $x = 0$ and $x = 1$ emerge.

This model assumes intense communication among the members of a information network. Women not only have to disclose their choices, but also must reveal their utility and their (not observable) individual characteristic ϵ. Under these strong conditions sufficiently large sample sizes imply one unique limit for contraceptive prevalence that is close to the socially efficient outcome. This argument suggests that an improvement of the information content that is transmitted in social networks is an alternative to an increased number of initial users to ensure long-term efficiency of information diffusion.

6 Conclusions

This paper investigates the diffusion of contraceptive knowledge through word-of-mouth communication as an example for 'learning in informal networks.' It is argued that women's conversations about fertility control are 'incomplete': communications inform only partially about a method's performance, and they give rise to unobserved heterogeneity among network partners. In this context the dynamic implications of social learning depend on the behavioral assumptions about contraceptive decisions. These assumptions are reflected in the decision rules that link a woman's contraceptive choice to her personal characteristics and the information she obtained through network partners.

An analysis of the 1973 Korean survey on women's social networks suggests that the proportion of pill-users among friends is a good predictor for a woman's probability to adopt the pill. The theoretical section develops three decision rules that are compared to this empirical finding. The majority rule assumes that women do not consider private information in their contraceptive decisions and simply adopt the most popular alternative among their friends. This rule leads to a 'snowball' effect in which one method rapidly emerges as the dominant contraceptive in the population. However, the majority model is not consistent with the micro-evidence in the Korean data, nor with long-term heterogeneity among regions. The empirical 'invalidity' of this model in combination with the subsequent analyses shows that the diffusion of contraceptive knowledge may not be pervasive, even when the newly introduced method is indeed superior.

The paper proposed as an alternative specification a qualitative choice rule. In this rule women infer the differential effectiveness of the contraceptive methods from their network information, and combine this inference optimally with their personal characteristics. This model predicts the pattern observed in the Korean data. The model is also consistent with a prevailing heterogeneity in contraceptive practices among regions or villages, and with a co-existence of methods within the same network. The long-term implications of this rule for the diffusion of contraceptive knowledge are robust against small modifications such as the introduction of observed heterogeneity, or random sizes of social networks. For the design of family planning programs this section suggests that the initial size of users is more important for a successful diffusion than the size of each woman's social network. The independent evolution of contraceptive use across observable characteristics emphasizes the necessity to establish an 'initial base' of contraceptive users in all social groups.

A final section illustrates the implications when women communicate their experienced utility level and all personal characteristics. This revealed utility model shows that with 'complete' communication the long term outcome of social learning is close to the social optimum. Improvements in the information content of women's conversations are therefore an alternative to ensure long-term social efficiency in information diffusion.

Table 1: Extent and content of social networking about fertility control

	average number of neighbors who are perceived to use		
	Loop	Pill	Condom or vasectomy
all women	2.61	2.27	1.82
umc-women using			
Loop	5.14	2.42	2.00
Pill	3.30	4.53	2.74
Condom or Vasectomy	2.90	3.05	4.49

Notes: The actual survey used the categories 'don't know any', 'know 1-2 women', '3-4 women', '5-6 women', and 'more than 7 women'. These categorical responses were converted into numeric values by taking the mean of the first four categories, and eight women for the open ended category.

Table 2: umc-women grouped by the proportion of pill users among umc-friends

(1) proportion of pill users among umc-friends (group mean in parenthesis)	(2) number of of umc-women	(3) proportion of umc-women in group	(4) average number of umc-friends among	(5)
			pill-users	non-pill-users
0 to 0.04 (0.0)	93	0.129	3.2	6.4
0.05 to 0.2 (0.15)	15	0.133	8.0	10.6
0.2 to 0.34 (0.303)	57	0.351	17.7	15.3
0.35 to 0.49 (0.415)	37	0.432	16.3	14.8
0.5 to 0.64 (0.537)	32	0.406	10.3	10.8
0.65 to 0.94 (0.76)	10	0.70	6.6	7.2
0.95 to 1 (1.0)	24	0.667	3.6	4.6

Notes: umc-women: 268 women living in 25 rural villages using modern contraception at time of the survey; umc-friends: friends and neighbors who are perceived to use modern contraception by the decision maker.

Table 3: Logit regressions for the 268 umc-women for the dependent variable women uses the pill.[a,b] Model 1: Logit regression. Model 2: Maximum likelihood estimation based on equation 1.

Variable	Parameter	Model 1	Model 2
(constant)	β_0	-4.4423	-0.8712
		(2.6663)	(3.2694)
age of woman	β_1	0.0152	0.0026
		(0.1149)	(0.1431)
number of living children	β_2	0.4135*	0.1871
		(0.1913)	(0.2296)
excess fertility	β_3	0.3445*	-0.1654
		(0.1638)	(0.1863)
education: attended at least elementary school	β_4	-0.1434	0.1147
		(0.3978)	(0.5624)
$\frac{m}{K}$ (proportion of pill users among umc-friends)	γ	2.4720**	-
		(0.5840)	
$\ln \frac{m}{K-m}$ (Log of ratio pill-users to non-pill users among umc-friends)	γ	-	0.9598**
			(0.3531)
(parameter of π)	α_0	-	-0.9524**
			(0.3542)
(parameter of π)	α_1	-	-0.1859**
			(0.0832)
village dummies		not reported[c]	-

Notes: (a) The regression includes 268 women who use modern contraception (loop, pill, condom, vasectomy) and know at least one umc-friend. Excess fertility is the difference between the number of living children and her desired number of children as stated in the survey. (b) Standard errors are given in parenthesis, and p-values are indicated as: * $P < 0.05$; ** $P < 0.01$. (c) The dummies for villages 15 and 17 could not be estimated because women in these villages used only one contraceptive method. The 25, 50, and 75 percentile for the village dummies are 0.698, 1.28, 1.97 respectively, and 6 out of 22 dummies are significant at the 5 percent level.

Table 4: Majority rule model and qualitative choice model: probability of dominance by one method for $\gamma_0 = 10$ and $X_0 = 0.6$

number of decisions	Majority rule		Qualitative choice rule	
	Probability of more than 80% of women using			
	method T	method M	method T	method M
$n = 10$	0	0	0.0	0.0
$n = 20$	0	0.741	0.0	0.022
$n = 40$	0.015	0.89	0.0	0.046
$n = 80$	0.031	0.93	0.001	0.064

Figure 1: Umc-women grouped by the proportion of pill users among umc-friends

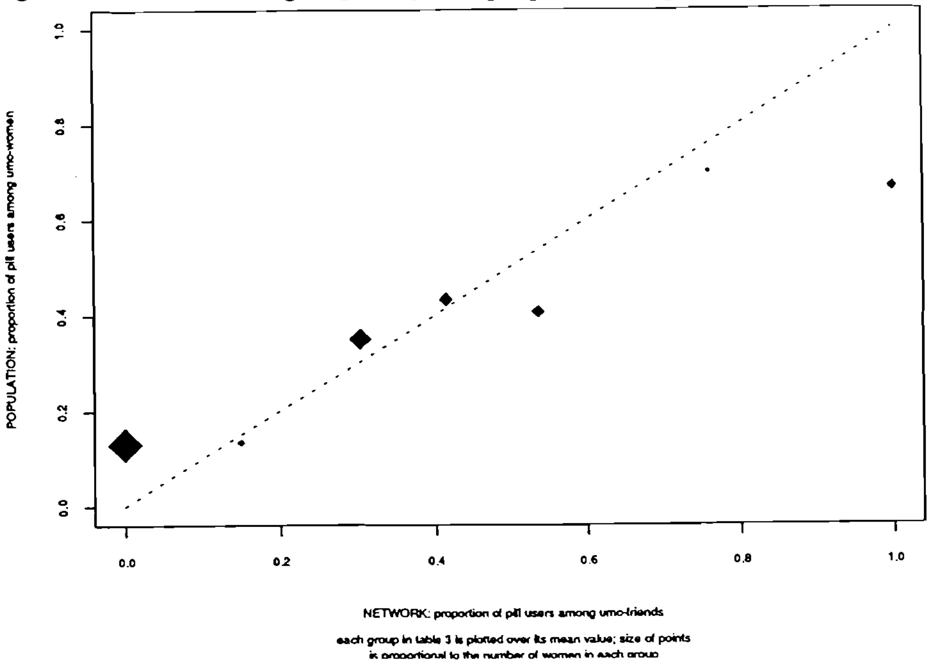


Figure 2: Majority based decisions: $q(x)$ for various values of K and α

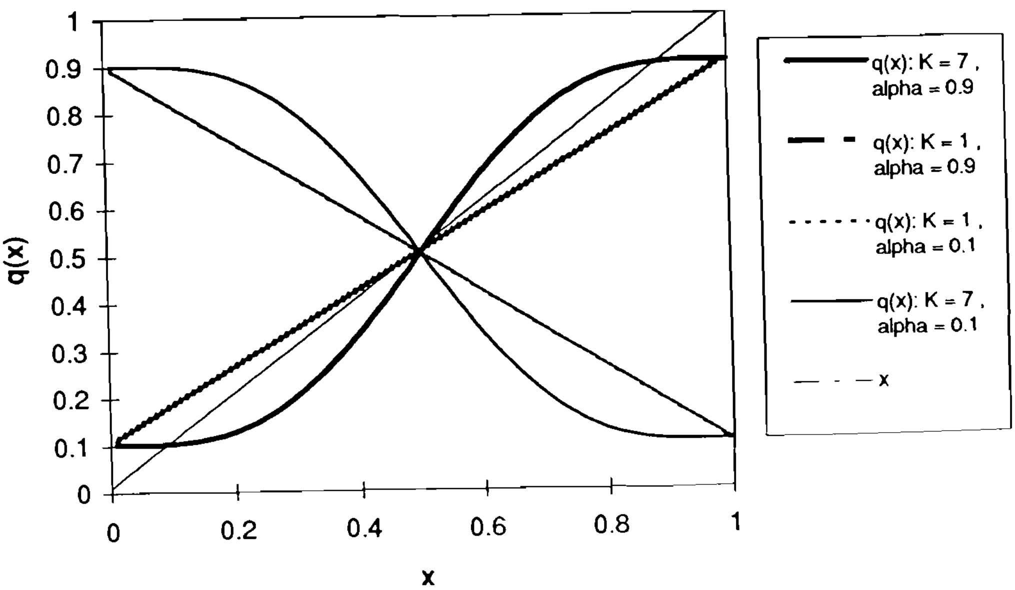


Figure 3: Histogram of the proportion of pill-users in 25 Korean villages

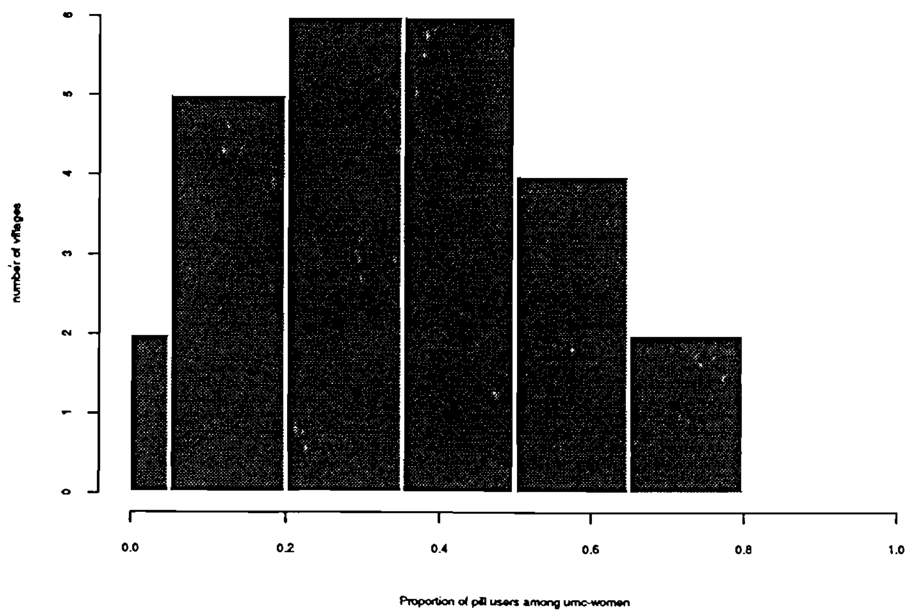


Figure 4: Probability distribution for the proportion of M users after 10 to 200 decisions

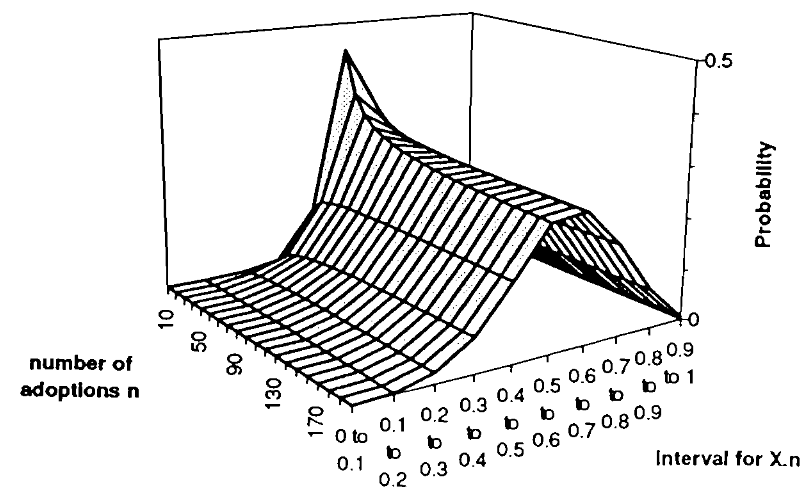


Figure 5: Limiting beta distribution of X_n. ($X_0 = 0.6$, $\gamma_0 = 10$ or 100, sampling is with replacement)

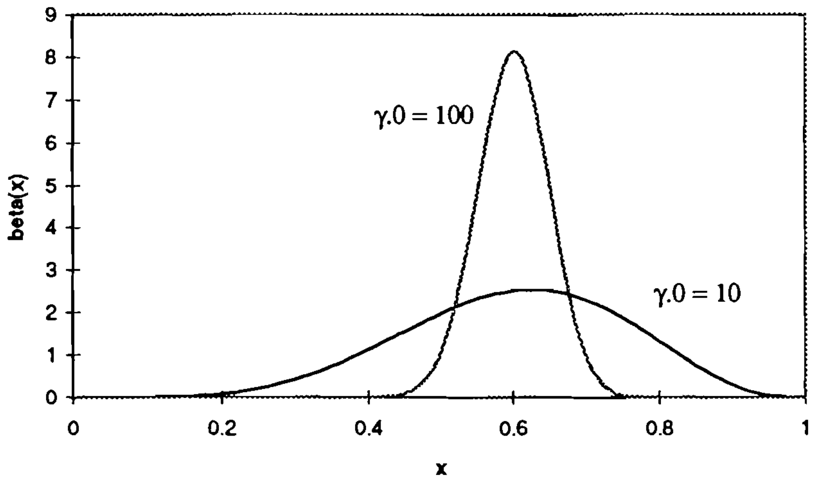
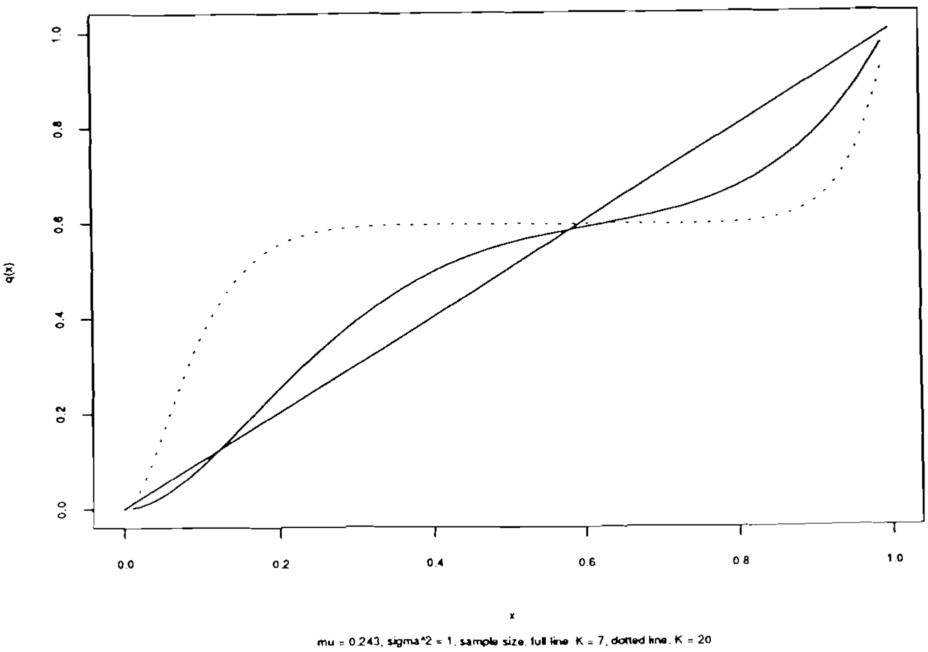


Figure 6: Urn function for revealed utility model



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