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A conceptual model for the prediction of sexual intercourses in permanent couples

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A conceptual model for the prediction of sexual intercourses in permanent couples

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Key words: mathematical models, conceptual models, frequency of intercourses, sexual appetite, erotic potential, parameter identifiability, universal model, Martin's law.

Abstract

The problem of the frequency of sexual intercourses in permanent couples is investigated for the first time with a purely conceptual model. The model, based on a few axioms involving very simple notions like sexual appetite and erotic potential, is composed of two ordinary differential equations which are exactly the same than those proposed almost one century ago in epidemiology. The model can be used to discuss the possibility of estimating strategic parameters from real data, as well as to criticize the rule of “the beans in the yar” proposed in 1970 by David Martin in The Journal of Sex Research.

Key words: mathematical models, conceptual models, frequency intercourses, sexual appetite, erotic potential, parameter identifiability, universal model, Martin’s law.

1 Introduction

So far, the frequency of sexual intercourses has been studied empirically, i.e. on the basis of data mainly reported by women (see [1] for a recent review) or sometimes by couples (see [2] for an example). Some contributions deal with rather special cases, like violent marriages [3] or single women [4], but the majority of studies deal with permanent couples [1] which is, indeed, the case we consider in this paper. In all these studies the focus is on the influence of one or more factors on the rate of sexual intercourses. The most frequently discussed factor is the life-time of the couple and the result on which most authors agree is that sexual activities within a given couple decline over time, in particular in the long term, but sometimes increase in the first phase of the life of the couple ([1],[5],[6],[7],[8]). Interesting results have also been obtained for many other factors such as man and women age ([2],[5],[6],[7]), availability of full-time jobs for women [2], state of health [6], premarital experiences [6], educational level [7], and fertility-related practices ([5], [7]). In all the above mentioned studies the models are empirically derived from standard statistical analysis (e.g. correlation analysis, linear regression, and multivariate analysis) performed on available data. Perhaps the only exception to the dominance of empirical models are two contributions ([9], [10]) in which the law of diminishing marginal utility and human capital theory are used in conjunction with statistical analysis. This is rather surprising, because in many other fields of science like, for example, economics, demography and ecology, conceptual deterministic models derived from general axioms (often conjectured without the use of data) are sometimes even more appreciated than empirical models based on data. Since there is no reason to believe that conceptual models can not be powerful descriptive tools also in sexology, we present in this paper a first conceptual model for the description of the dependence of the rate of sexual intercourses upon the life-time of the couple.

The paper is organized as follows. In the next section three conjectures on erotic potential, sexual appetite and rate of sexual intercourses are proposed and a parameterized family of conceptual models in the form of ODE's is explicitly derived from them. The model clearly points out that the rate of sexual intercourses first increases and then decreases in couples initially endowed with a high erotic potential. Then, in the third section the identifiability of the parameters of the model from available data is discussed, while in the fourth section the entire family of conceptual models is shown to be represented, after a simple rescaling of the variables, by a universal model from which general properties can be derived. In the fifth section, in order to show at least one application of our conceptual model, the famous rule of the 'beans in the yar' [11] is first slightly reformulated and then criticized. Limitations of the model, as well as possible extensions and applications, are shortly discussed in the last section.

2 The Model

Conceptual models are based on a number of simplifying assumptions that are often quite crude with respect to reality. In the case examined in this paper, in order to minimize the dimensions of the model, i.e. the number of variables and equations involved, our assumptions are actually extreme. First of all, we consider the couple as a compact unit endowed at any time τ with an erotic potential $X(\tau)$, a sort of hidden resource that is consumed through sex activity. Thus, we can not distinguish between the two partners and we are, therefore, forced to describe the sexual appetite of the couple with a single variable $Y(\tau)$. Moreover, details on the quality and diversity of sexual activities are not considered, so that the rate of sexual intercourses $Z(\tau)$ must simply be imagined as the number of standard sexual intercourses per unit time. Age and social environment are also not taken into account in order to obtain a time-invariant model, i.e. ODE's with constant parameters.

Under these assumptions, a conceptual model is nothing but a set of conjectures (often called axioms) on the relationships existing among the variables $X(\tau)$, $Y(\tau)$, and $Z(\tau)$. Of course, many are the possible conjectures, and some of them may be a priori more reasonable than others in particular contexts, for example, when applied to couples with specific cultures. Here we only pretend to give a first example of conceptual models and therefore focus on three very simple conjectures :

1. The rate of consumption of erotic potential through sex is proportional to the erotic potential itself, as well as to the rate of sexual intercourses.

2. Sexual appetite is renewed by the consumption of erotic potential and reduced by sexual intercourses.

3. The rate of sexual intercourses is proportional to sexual appetite.

In formulas, the first two conjectures can be written as

$$\frac{\partial X(\tau)}{\partial \tau} = -\alpha X(\tau) Z(\tau) \tag{1}$$

$$\frac{\partial Y(\tau)}{\partial \tau} = -\beta \frac{\partial X(\tau)}{\partial \tau} - \gamma Z(\tau) \tag{2}$$

while the third conjecture is simply

$$Z(\tau) = \delta Y(\tau) \tag{3}$$

In model (1-3) ($\alpha, \beta, \gamma, \delta$) are four behavioral parameters characterizing the couple. In reality, these parameters should be time-dependent but here they are assumed to be constant.

The third equation can be used to eliminate Y from the second differential equation and the result is

$$\begin{aligned} \frac{\partial X(\tau)}{\partial \tau} &= -\alpha X(\tau) Z(\tau) \\ \frac{\partial Z(\tau)}{\partial \tau} &= \alpha\beta\delta X(\tau) Z(\tau) - \gamma\delta Z(\tau) \end{aligned}$$

Letting

$$a = \alpha, \qquad b = \alpha\beta\delta, \qquad c = \gamma\delta,$$

the model becomes

$$\frac{\partial X(\tau)}{\partial \tau} = -aX(\tau)Z(\tau) \tag{4}$$

$$\frac{\partial Z(\tau)}{\partial \tau} = bX(\tau)Z(\tau) - cZ(\tau) \tag{5}$$

Surprisingly, model (4, 5) has the same form than the first epidemic model proposed long ago [12]. Notice that the knowledge of the three parameters (a, b, c) identifying model (4, 5) does not allow one to uniquely identify the four behavioral parameters ($\alpha, \beta, \gamma, \delta$) introduced with the three conjectures.

The solution of system (4, 5) can not be obtained in closed form, but the trajectories in the state space (X, Z) (easily derivable through the method of isoclines, as shown in Fig.1) point out a number of interesting properties. All trajectories move from the right to the left since $\partial X(\tau)/\partial\tau$ is always negative (i.e. the erotic potential can only be eroded), while $Z(\tau)$ first increases if

$$X(0) > \frac{c}{b} \tag{6}$$

and then decreases. The rate of sexual intercourses is maximum when the erotic potential is equal to the characteristic value $c/b = \gamma/(\alpha\beta)$. Thus, if the couple is initially endowed with a too low erotic potential, i.e. if (6) is not satisfied, then the sexual activity declines from the beginning, while in the opposite case it first increases and then declines (see Fig. 1). As already said in the Introduction, both possibilities are confirmed by data ([1],[5],[6],[7],[8]). All trajectories tend asymptotically toward the segment ($0, c/b$) of the X axis. In other words, sooner or later the erotic potential falls below the critical threshold c/b and all erotic activities first decline and practically cease shortly after. It is interesting to note that many, if not all, suggestions given in the technical literature to enhance sexual activities of depressed couples can be viewed as ways of reducing the threshold $c/b = \gamma/(\alpha\beta)$ or regenerating the erotic potential of the couple through various actions (sport, drugs, psychoanalysis, ...).

3 Parameter Estimation

Since the three parameters (a, b, c) characterizing model (4, 5) cannot be specified a priori, it is interesting to know if they can be estimated from quantitative informations on the sexual activities of a given couple. In the present case, it is reasonable to assume that the available data concern only the rate of sexual intercourses since erotic potential and sexual appetite are hidden variables. Thus, in order to estimate the parameters (a, b, c), one should first derive from model (4, 5) a differential equation involving only the variable $Z(\tau)$ and then use it to find the values of the parameters for which the solution of the differential equation is most consistent with the data. The first step can be easily accomplished. In fact, by differentiating equation (5) with respect to time, one obtains

$$\frac{\partial^2 Z}{\partial \tau^2} = bZ\frac{\partial X}{\partial \tau} + bX\frac{\partial Z}{\partial \tau} - c\frac{\partial Z}{\partial \tau}$$

where X and $\partial X/\partial \tau$ can be replaced by

$$X = \frac{1}{b}\left(\frac{1}{Z}\frac{\partial Z}{\partial \tau} + c\right), \quad \frac{\partial X}{\partial \tau} = -\frac{a}{b}\left(\frac{\partial Z}{\partial \tau} + cZ\right)$$

where the first relationship is directly obtained from (5), while the second one takes also (4) into account. The result is the following second order differential equation

$$\frac{\partial^2 Z}{\partial \tau^2} + \left(aZ - \frac{\partial Z}{\partial \tau}\right)\frac{\partial Z}{\partial \tau} + acZ^2 = 0 \qquad (7)$$

which is a model involving only the rate of sexual intercourses and its first two time derivatives. It is important to notice that only two parameters, namely a and c, appear in model (7). This means that data on the time evolution of the rate of sexual intercourses do not allow one to estimate the parameter b which is therefore not identifiable. Thus, information on $Z(\tau)$ can be used to estimate only the behavioral parameter α, introduced with the first conjecture, and the product $\gamma\delta$ of two other behavioral parameters introduced with the second and third conjectures.

The choice of the algorithm one could/should use to obtain a satisfactory estimate ($\hat{a}, \hat{c}$) of the parameters (a, c) largely depends upon the quantity and quality of available data. In extreme cases, when data are very scarce, the estimate ($\hat{a}, \hat{c}$) can be obtained by finding the values of (a, c) that force the solution $Z(\tau)$ of equation (7) to pass through a given number of points. For example, let us assume that for each sufficiently mature couple of a given population we have obtained the following informations: the year T_{max} during which the couple had the most intensive sexual activity measured by Z_{max} (maximum numbers of intercourses per week) of intercourses, and the years T^I ($< T_{max}$) and T^{II} ($> T_{max}$) during which the couple had a sexual activity about one half the maximum. Given these informations, one can fix a and c and integrate equation (7) backward and forward starting at time T_{max} with

$$Z(T_{max}) = Z_{max} \qquad \frac{\partial Z}{\partial \tau}(T_{max}) = 0$$

Then, one can check if

$$Z(T^I) = \frac{Z_{max}}{2} \qquad Z(T^{II}) = \frac{Z_{max}}{2} \tag{8}$$

and, if not, vary a and c in a suitable way until the test (8) is, at least approximately, satisfied.

It can be that the estimation procedure must be repeatedly applied to a high number of couples belonging to a given population, with the aim of determining the mean values of the parameters a and c of the entire population. In such a case, it would be advisable to produce a series of charts like that shown in Fig.2 for each value of

Z_{max} on a grid (e.g. $Z_{max} = 1, 2, 3, ...$). For example, the chart in Fig. 2 corresponds to $Z_{max} = 3$ and displays a few curves in the plane (a, c) on which $(T_{max} - T^I)$ is constant (and equal to 2,3,4,5 years) (dotted curves) as well as curves on which $(T^{II} - T_{max})$ is constant (and equal to 2,3,4,5 years) (continuous curves). Note that these curves point out that, in general, $T_{max} - T^I < T^{II} - T_{max}$. Then, these charts can be used in an obvious way to produce an estimate ($\hat{a}, \hat{c}$) of (a, c) for any couple. For example, if a couple is characterized by

$$Z_{max} = 3 \qquad T_{max} - T^I = 3 \qquad T^{II} - T_{max} = 4$$

one can immediately say from the chart in Fig.2 that

$$\hat{a} \cong 0.0582 \qquad \hat{c} \cong 0.693$$

It is interesting to note that a detailed analysis of this estimation procedure shows that, for couples with non exceedingly low sexual activity ($Z_{max} > 0.25$, i.e. at least one intercourse per month at the peak of sexual activity), the estimate $(\hat{a}, \hat{c})$ depends much more on $(T_{max} - T^I)$ and $(T^{II} - T_{max})$, than on Z_{max}, at the point that the information on Z_{max} is almost irrelevant.

If model (7) is discretized with respect to τ with a one year time step, a recursive model of the kind

$$N_{k+1} = f\left(a, c, N_k, N_{k-1}\right)$$

is obtained, where N_k is the number of sexual intercourses in year k. This model can virtually be used at the end of each year k to predict the number $\hat{N}_{k+1}$ of intercourses in the next year by substituting N_k and N_{k-1} with the real numbers $\bar{N}_k$ and $\bar{N}_{k-1}$ of sexual intercourses (which are known at the end of year k)

$$\hat{N}_{k+1} = f\left(\hat{a}, \hat{c}, \bar{N}_k, \bar{N}_{k-1}\right) \tag{9}$$

If the aim of these predictions is to forecast the sexual activities of an entire population (for example, in order to correlate with the birth rate of the population) one should estimate the parameters a and c and then apply model (9) to each couple of the population, because the nonlinearity of the function f prevents any sort of aggregation. This points out very clearly that the diversity of the behavioral characteristics of the components of a population can not be neglected in making predictions at a population level (this remark puts some shadow on many available contributions).

4 A Universal Model

A classical suggestion, when playing with conceptual models depending upon a set of parameters, is to rescale the variables (time, erotic potential and rate of sexual intercourses in the present case) in order to aggregate the original parameters in a smaller number of new parameters [13]. This procedure reduces the number of parameters and therefore simplifies the analysis. In the most lucky cases, like the present one, the rescaled model has no parameters and is therefore a sort of 'universal' model. Once the solution of the universal model is known, the solution of the original model can be immediately obtained through the inverse rescaling of the variables. Let us apply this idea to our model (4, 5) by rescaling τ, X, and Z as follows

$$t = \mu_t \tau \qquad x = \mu_x X \qquad z = \mu_z Z$$

Thus, model (4, 5) becomes

$$\frac{\partial x}{\partial t} = \frac{\mu_x \partial X}{\mu_t \partial \tau} = \frac{\mu_x}{\mu_t}(-a)\frac{x}{\mu_x}\frac{z}{\mu_z} = -\frac{a}{\mu_t \mu_z} xz$$

$$\frac{\partial z}{\partial t} = \frac{\mu_z \partial Z}{\mu_t \partial \tau} = \frac{\mu_z}{\mu_t}\left(b\frac{x}{\mu_x}\frac{z}{\mu_z} - c\frac{z}{\mu_z}\right) = \frac{b}{\mu_t \mu_x} xz - \frac{c}{\mu_t} z$$

and if the three rescaling factors (μ_t, μ_x, μ_z) are fixed at the values

$$\mu_t = c \qquad \mu_x = \frac{b}{c} \qquad \mu_z = \frac{a}{c}$$

then the rescaled model simplifies to

$$\begin{aligned} \frac{\partial x}{\partial t} &= -xz \\ \frac{\partial z}{\partial t} &= xz - z \end{aligned} \tag{10}$$

which is, obviously, a universal model.

Some trajectories of the universal model (10) are shown in Fig.3. They start infinitely close to the x-axis at a point with coordinate x_0 and tend asymptotically toward another point of the x-axis with coordinate x_∞. Thus, x_0 is the initial endowment of erotic potential, while x_∞ is what remains when sexual activities have ceased. It is interesting to note that although the map $x_0 \mapsto x_\infty$ can not be analytically derived, a simple geometric procedure for computing x_∞ from x_0 can be obtained. In fact, from system (10) we can write

$$\frac{\partial z}{\partial t} = -\frac{\partial x}{\partial t} + \frac{1}{x}\frac{\partial x}{\partial t}$$

which can be integrated from $t = 0$ to $t = \infty$, thus giving

$$z_\infty - z_0 = x_0 - x_\infty + ln(x_\infty) - ln(x_0)$$

But $z_0 = z_\infty = 0$, so that x_0 and x_∞ satisfy the following relationship

$$x_0 - x_\infty = ln(x_0) - ln(x_\infty) \tag{11}$$

Equation (11) is geometrically interpreted in Fig.4-(a) where it is shown how one can derive the map $x_0 \mapsto x_\infty$ represented in Fig.4-(b).

5 Comparison with Martin's Rule

In 1970 David Martin published a paper in The Journal of Sex Research entitled 'Note on a mathematical "theory" of coital frequency in marriage'. The paper starts as follows 'An old folk theory of the sex lives of married couples goes roughly thus : Starting on your wedding night and continuing through the first year of your marriage, put one bean in a jar for every time you have intercourse. Starting with the beginning of your second year of marriage, take one bean out of the jar for every time you have intercourse. When you die there will still be some beans left in the jar.' Although Martin himself qualifies his rule as a "folk" theory, he tried to support it with some theoretical arguments but unsuccessfully. This is not surprising since the idea of reversing the flow of the beans after one year does not make any sense, because nothing particularly significant happens at that precise moment. By contrast, the analysis of our model has shown that in all couples endowed with a sufficiently high initial erotic potential the rate of sexual intercourses reaches a maximum Z_{max} at a time T_{max} (different for each couple). Thus, since T_{max} has a precise physical meaning it would make sense to modify Martin's rule by inverting the flow of the beans at that time. In other words we can split the life of the couple into two phases, namely one before and one after the peak of sexual activity and define the total sexual activities in the two phases as

$$N^I = \int_0^{t_{max}} z(t)dt \qquad N^{II} = \int_{t_{max}}^{\infty} z(t)dt$$

where $t_{max} = \mu_t T_{max} = cT_{max}$. Then, we can reformulate Martin's rule as

$$N^I > N^{II} \tag{12}$$

Using our conceptual model (10) we can easily check that the reformulated Martin's rule (12) is false since the opposite inequality actually holds true. In fact, in view of the first equation of system (10) we have

$$N^I = \int_0^{t_{max}} z(t)dt = -\int_0^{t_{max}} \frac{1}{x}\frac{\partial x}{\partial t}dt = ln(x_0) - ln(x(t_{max})) = ln(x_0)$$

because $x(t_{max}) = 1$, and, similarly,

$$N^{II} = \int_{t_{max}}^{\infty} z(t)dt = -\int_{t_{max}}^{\infty} \frac{1}{x}\frac{\partial x}{\partial t}dt = -ln(x_\infty) + ln(x(t_{max})) = -ln(x_\infty)$$

and the geometric procedure described in Fig.4-(a) shows that $N^I < N^{II}$ even if the difference between N^{II} and N^I is quite small in couples with not too high erotic potential. The exact comparison of N^I with N^{II} can be done using the map $x_0 \mapsto x_\infty$ already determined (see Fig. 4-(b)) and the result is shown in Fig.5. This conclusion reduces the enthusiasm for Martin's rule even in its revised version (12). One could notice, however, that our mathematical analysis is definitely biased against Martin's rule, because the real number of intercourses in the declining phase of a couple is certainly smaller than our N^{II}, first because life is not infinitely long (as in our analysis) and second because the sexual performances decline with age for physiological reasons (a fact not considered in our model which has constant parameters). Thus, it might be that Martin's rule is not as far from the truth as it appears to be by looking at Fig.5.

6 Concluding Remarks

The time evolution of the rate of sexual intercourses has been discussed until now only empirically, i.e. through detailed statistical analysis of available data. From many of these studies it emerges that sexual activities decline over time in particular in the long term, but can sometimes increase in the first phase of the life of a couple. One can reasonably suspect that properties of this kind might be the mere consequence of psycho-physiological behavioral characteristics of the partners. If so, they should be derivable on a purely logical basis (i.e. without the use of data) from a few axioms describing the characteristics of the couple. This is what we have shown in this paper by presenting a so-called conceptual model, namely a set of axioms describing in mathematical terms the conjectured relationships between erotic potential, sexual appetite and rate of sexual intercourses. Since this seems to be the first time that a conceptual model is proposed in this field, we have used a rather simple and scholastic style of presentation and shown how a conceptual model can be used to identify behavioral parameters from available data, forecast in real-time the sexual activities of a couple, derive universal properties, and criticize ”folk” rules like that of the ‘beans in the jar’ [11] reported in a popular science book on sex and mathematics [14].

We must confess that we are not too proud of our model which is not particularly profound or innovative and, actually, has many limitations, like the independence upon age of the behavioral parameters and the fusion of the partners into a single unit. By contrast, we believe that the presentation of a first conceptual model is of great potential value because it shows how a problem investigated empirically until now, can also be attacked from a purely dogmatic point of view. This way of approaching problems is actually very common in economics and in many sectors of biology, like population dynamics, and there is no reason it should not be effective also in sexology.

Since the proposed model has serious limitations we believe that some extensions are worth to be considered. Among them we can suggest the study of the same model with time-varying parameters that could mimic the influence of seasonalities (holidays) or the decline with age of some physiological characteristics. A more difficult but promising extension would be to describe the two partners separately, in order to have the possibility of discussing gender differences [15].

But even if the model discussed in this paper is crude and naive, it could already be used in its present form to improve the studies performed in the last decades on love dynamics ([16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26]). In all these modeling studies, the parameters are constant and some of them interpret the sexual appetite of the individuals. Thus, on the basis of what we have learned in this paper, we could improve those models by simply adding to them the differential equations ((4),(5)) and equation (3) to generate a time-varying sexual appetite. As already argued ([17, 26]) this simple but strategic modification could explain interesting phenomena observed in real life like the emergence of ups and downs of the feelings in young couples and the disappearance of this turbulence when the couple reaches a certain age.

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Figure captions

Figure 1

Time evolution of erotic potential (X) and frequency of sexual intercourses (Z) predicted by model (4,5).

Figure 2

Chart obtained with $Z_{max} = 3$: dotted curves are curves with constant $T_{max} - T^I$ (2,3,4,5 years), while continuous curves are curves with constant $T^{II} - T_{max}$ (2,3,4,5 years).

Figure 3

Trajectories of the universal model (10).

Figure 4

Relationship between initial (x_0) and final (x_∞) erotic potential in the universal model (10): (a) geometric interpretation of the relationship; (b) the map $x_0 \mapsto x_\infty$.

Figure 5

Total number of intercourses before (N^I) and after (N^{II}) the peak of sexual activity of the couple as a function of the initial endowment of erotic potential (x_0).

Figures

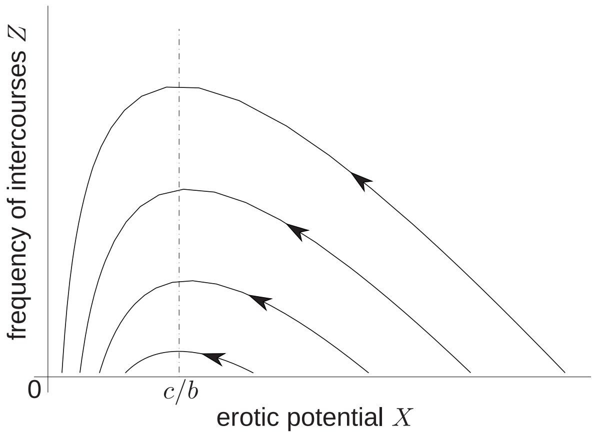


Figure 1

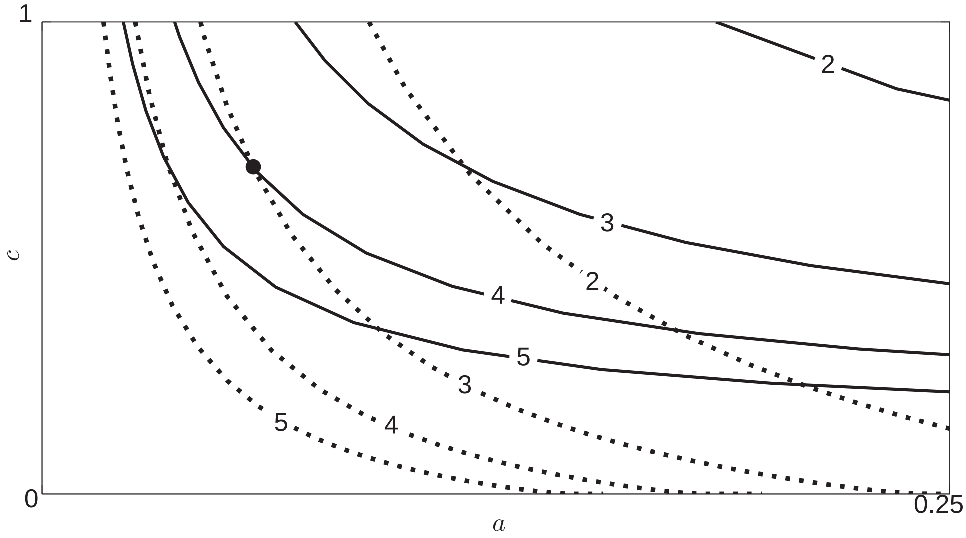


Figure 2

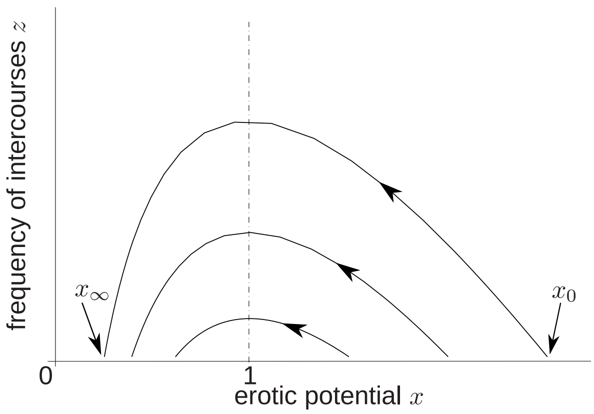
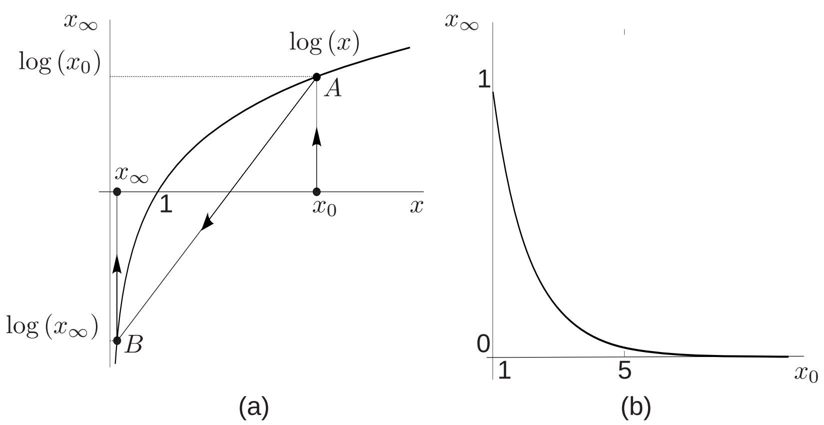
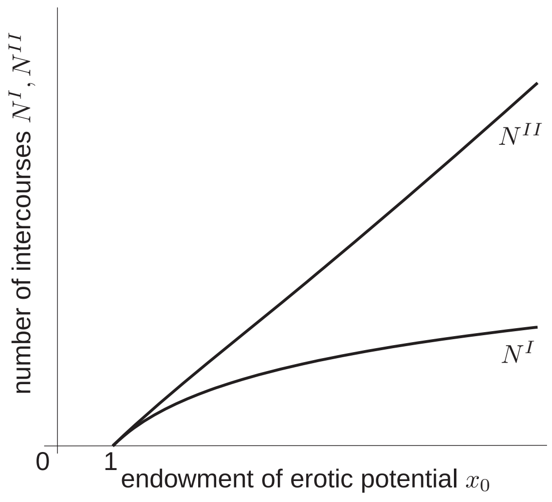

frequency of intercourses z
x_∞
x_0
0
1
erotic potential x

Figure 3



x_∞
$\log(x_0)$
$\log(x)$
A
x_∞
1
x_0
x
$\log(x_\infty)$
B
(a)
x_∞
1
0
1
5
x_0
(b)

Figure 4



number of intercourses N^I, N^{II}
N^{II}
N^I
0
1
endowment of erotic potential x_0

Figure 5