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Review Article

Modeling reproductive decisions with simple heuristics

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Modeling reproductive decisions with simple heuristics

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Abstract

BACKGROUND

Many of the reproductive decisions that humans make happen without much planning or forethought, arising instead through the use of simple choice rules or heuristics that involve relatively little information and processing. Nonetheless, these heuristic-guided decisions are typically beneficial, owing to humans' *ecological rationality* – the evolved fit between our constrained decision mechanisms and the adaptive problems we face.

OBJECTIVE

This paper reviews research on the ecological rationality of human decision making in the domain of reproduction, showing how fertility-related decisions are commonly made using various simple heuristics matched to the structure of the environment in which they are applied, rather than being made with information-hungry mechanisms based on optimization or rational economic choice.

METHODS

First, heuristics for sequential mate search are covered; these heuristics determine when to stop the process of mate search by deciding that a good-enough mate who is also mutually interested has been found, using a process of aspiration-level setting and assessing. These models are tested via computer simulation and comparison to demographic age-at-first-marriage data. Next, a heuristic process of feature-based mate comparison and choice is discussed, in which mate choices are determined by a simple process of feature-matching with relaxing standards over time. Parental investment heuristics used to divide resources among offspring are summarized. Finally, methods for testing the use of such mate choice heuristics in a specific population over time are then described.

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1. Introduction

Humans make a variety of reproductive decisions throughout their lives, with the most important including who to choose as a mate, when to have offspring with that mate, and how to raise the children that result. Some of these decisions are consciously planned with great deliberation; others (probably the majority) may come about without deep thought, guided instead by simple strategies or rules of thumb and shaped by external environmental factors. And yet these common, less planned, more intuitive decisions often work out well in terms of reproductive success, leading to healthy members of the next generation. This happens despite the great uncertainty that may surround determining who will be a good mate or what is an appropriate way to provision one's children, and without needing to gather a lot of information about the possible courses of action before choosing a mate. In this paper, we outline some of the ways that simple heuristics can be used in making reproductive decisions, and how they can be studied. We begin with an overview of the perspective of *ecological rationality* within which this research is situated, before proceeding to cover investigations of heuristic rules for mate search and choice, parental provisioning of individual offspring, and decisions related to fertility.

This research program on simple heuristics and their effectiveness in appropriate settings represents a new approach to questions in demographics. First, it builds a theoretically motivated, psychologically grounded framework for predicting and understanding population-level patterns of fertility-related behavior, based on the individual-level decision mechanisms that people actually use. Rather than the economists' vision of human decision making employing all of the available information, fully known preferences, and fully processed implications of both, simple heuristics are built on realistic assumptions of the limited information, time, and thinking that people are actually able to bring to bear on most of their choices. Second, this research program uses simulation models of these simple decision heuristics, in conjunction with empirical data from experiments and field observations, to test the effectiveness of the heuristics in different situations and their implications at the population level. In this way, we can investigate our assumptions about the rules people use and thereby develop the theory and insights relevant to demographics in an iterative fashion. Both of these facets will be illustrated through the specific examples detailed in the following sections.

2. The ecological rationality perspective on decision making

How can good decisions be made by human minds operating in an uncertain world? This is a mystery because, like other animals, humans must make decisions within the rather severe bounds that our minds and the world impose on us. These bounds include the limited time that we have to make decisions before an opportunity may be gone, the limited and uncertain information we can access within that time, and the limited ability we have to process that information, owing to constraints of memory, processing speed, and the amount of complexity we can deal with. Each of these bounds is relevant to the reproductive decisions listed above.

To work within these bounds and still behave adaptively, agents can rely on simple “fast and frugal” heuristics (Gigerenzer and Goldstein 1996; Gigerenzer, Todd, and the ABC Research Group 1999) – decision rules that use a small amount of time, information, and processing to come up with what are usually good choices, when they are employed in the proper environments. This use in appropriate environments is key to the heuristics’ successful application, because it allows them to exploit the fact that information we know about the world is typically structured in useful ways. For example, if you ask people what academic authors, or cities, or products they recognize, you will find that their recognition knowledge is systematic, reflecting objective aspects of the world such as publication rate, or population size, or prevalence of brands, rather than a random or uniform distribution of what is recognized (Gigerenzer et al. 1999). This structure of recognition knowledge holds in particular domains or environments – namely, those where people tell each other about the important things in that domain, such as the successful authors, big cities, or exciting brands; in other environments, for instance where all the options are well known, recognition knowledge will not be correlated with environment structure. But in appropriately structured environments, this learned recognition knowledge can then be capitalized on by simple heuristics that employ recognition as a cue in making choices: for instance, when deciding what paper to cite or what brand to buy. In fact, by counting on certain information structures to be present in the environment, decision heuristics can be correspondingly simpler, effectively letting the world do some of the work for them.

Using simple heuristics in environments to which they fit can enable decision-making agents to achieve what Herbert Simon (1990) called *bounded rationality*. In contrast to the largely unachievable dream of unbounded rationality, which assumes optimal processing of all available information without concern for computational or informational costs, Simon saw humans as exhibiting a bounded form of rationality emerging from the interaction of two forces: the cognitive capabilities of the agent and the structure of the task environment. These two components should fit together like the two blades of a pair of scissors for adaptive, or boundedly rational, behavior to be

produced – that is, mind and environment should be closely matched if decision outcomes are to be useful. This perspective aligns well with that of evolutionary psychology, which adds the assumption that the mind–environment fit has been achieved by evolution honing the former to match the latter. But it is important to recognize that minds also shape their own environments, particularly in social domains, so that the adaptive forces flow in both directions between the organisms and their world.

Gigerenzer and colleagues (1999; Todd, Gigerenzer, and the ABC Research Group 2012) have taken up the challenge of identifying the particular decision mechanisms that can produce bounded rationality in the presence of particular structures of information in the environment. They call this research program ecological rationality, to emphasize the importance of considering both environmental information structure and psychological information-processing mechanisms, and how the former enables and constrains the latter to yield adaptive decisions. Their strategy for studying the ecological rationality of particular decision mechanisms follows a sequence of steps that largely mirrors the research plan for evolutionary psychology set out by Cosmides and Tooby (1987), proceeding through analysis of the decision environment and the structure of information available in it, simulation of proposed heuristic mechanisms to test how well they work in that particular environment, mathematical analysis of the information structures in which the proposed heuristics will and will not work well, and empirical investigation of when people actually use these heuristics. Through this process, we can build up a picture of the mind's adaptive toolbox of different simple heuristics and other decision strategies (including more complex and deliberate planning processes) that can be selected and used to solve the challenges facing an individual (or group) in different environmental settings (Gigerenzer et al. 1999).

The above principles of ecological rationality apply directly to mating and reproduction, because our mating and reproductive environments have long posed adaptive problems that call for effective decision strategies, but at the same time those environments are dynamic and largely unknowable. The social environments within which we make reproductive decisions change over time and much of the information that could be useful in making good mating choices is beyond the bounds of our personal experience or cannot be remembered and integrated completely into effective decisions when the time comes. This means that trying to optimize one's choice based on perfect knowledge of the mating environment is essentially impossible and potentially extremely costly. As a consequence, decision heuristics offer strong adaptive advantages for a variety of fertility-related decisions that individuals seeking mates must make. For example, individuals must estimate the quality of potential partners based on what they have learned about cues to mate quality from others they have interacted with in the past (in addition to innate and socially acquired knowledge), so

the particular vagaries of individual experience will have a great impact on the future choices made. Deciding how many children to have may be influenced by (not necessarily conscious) estimates of the impact of a given family size on one's reproductive success, including estimating the likelihood that a given offspring will survive to reproductive age. This will also be influenced by one's past experience, and appropriate experience in this regard will probably be even more limited than experience with respect to potential mates. Thus decisions about mate choices and having children will be based on the bounded information available in the individual's present and past (including personal, cultural, and evolutionary) environment and the bounded means with which the individual has to recall and process that information into appropriate choices.

In the next section we present some of the research on the heuristics in the adaptive toolbox that can be used to make particular reproductive decisions, focusing on the less planned decisions rather than the carefully deliberated ones. The theoretical perspective driving this work is that fertility-related decisions (like those in other domains) are commonly made using a number of different simple heuristics, specifically honed to the structure of the environment in which they are applied, rather than all being computed by omnipotent mechanisms of optimization or rational economic choice.

3. Ecologically rational approaches to fertility decisions

The ecological rationality study of heuristics related to reproduction has so far mostly been applied to how people choose their mates, the first step on the way to having children. Indeed, understanding the mate search process may go some way to helping us understand fertility, given their close linkage (e.g., as shown by the reduction in fertility that has accompanied the increase in age at first marriage). In sections 3.1 and 3.2 we describe research on this mate choice decision domain, both empirical and via computer simulation, and then in section 3.3 we discuss models of heuristics for parental investment – how decisions are made for dividing up resources among children being raised. Finally in section 3.4 we describe empirical and theoretical research on heuristics underlying the decision to have unprotected sex that may lead to children. (While here only the decisions regarding unprotected sex are considered in a sex-specific manner, of course the heuristic decision mechanisms used by men and women for mate choice and child rearing could also differ: for instance, in the cues used to make a choice or the thresholds applied for when a choice will be made; further elaborations of these models should explore such possible sex differences.)

3.1 Heuristics for mate choice and search

The task of mate choice can be broadly thought of as incorporating two steps, focusing on choosing (or not) a particular individual and deciding how long to search for a better partner: first, for each potential mate that is met, assessing the relevant cues of mate quality of that individual and processing those cues somehow into an overall judgment of the individual's mate quality (which will typically be relative to the searcher's own quality, traits, and preferences); and second, using that judged quality of the potential mate to guide the process of searching through a sequence of individuals, specifically deciding whether to court this particular individual or pass them by. Decision heuristics involving limited cue processing can be used in the first step, for deciding about a particular individual. For instance, the take-the-best heuristic (Gigerenzer and Goldstein 1996) can make choices about an individual, or between competing potential mates, on the basis of a single highly important cue. This heuristic does not gather and assess multiple pieces of information at once (as a traditional rational approach would dictate), but rather looks at single pieces of information – cues – one by one, checking to see whether each individual cue would indicate that one option is better than another. If so, then the information-search process is stopped right then, and the better option, as determined by that single cue, is chosen. For instance, if a mate-seeker is trying to decide whether a current potential prospect is enticing enough to pursue, she may assess the prospect's most important cue (to her), say his sense of humor, and see if that is better than the sense of humor of another prospect she has in mind (or some other standard she has built from past experience). If not, she may pass him by and continue her search; if so, she may decide to pursue him (at least to find out more); or if his humor is equal to her standard, then she may move to the next-most-important cue, perhaps warmth. Again, checking just that cue, if the prospect is worse, move on; if better, select; and if the same, then check the next cue. This cue checking continues until the first cue is encountered that allows a decision to be made. This simple heuristic minimizes the amount of information that must be assessed before a decision is made – only so many cues are considered until the first one is found that allows a choice. What cues are used and how they are ordered in the decision process will depend on a combination of evolved constraints, cultural inputs, and personal experience, and will typically differ somewhat between men and women (see, e.g., Li, Bailey, Kenrick, and Linsenmeier 2002). Another strategy, avoid-the-worst (Grammer et al. 2001), also makes comparisons between potential mates on the basis of a single cue, but orders the cues in the reverse direction, starting with consideration of the least attractive cues. This heuristic implies a more risk-averse strategy of avoiding undesirable mates. And of course, the mate choice process can be ongoing, with some cues being quickly perceived and used to decide whether to continue to spend time with a prospect, and other cues taking longer to assess (e.g., general mood or health level), which can result

in a decision to stay or go being made later in a relationship, leading to a decision mechanism that essentially uses a set of successive “hurdles” as cues that take longer to assess are observed (see Miller and Todd 1998).

Another simple approach to mate choice can even sidestep the reduced information-searching process of the take-the-best heuristic, by capitalizing on the great amount of potentially useful information acquired through the experiences of others in the surrounding social environment – namely, what and whom others find attractive. This leads to a different heuristic: select someone that others like (Todd, Place, and Bowers 2012). This mate choice copying strategy says, if someone else finds that potential mate worth pursuing, then you should, too. This form of social imitation has the benefit of removing the need to directly observe cues about a potential mate, instead letting others do the work. This is especially beneficial if those others have spent more time assessing the potential mate or are more experienced in judging mate quality (Dugatkin 2000). Evidence for such mate choice copying heuristics has recently been found in humans (Waynforth 2007; Place, Todd, Penke, and Asendorpf 2010). Such social imitation processes can also influence other fertility-related behaviors, such as deciding to have children (Christakis and Fowler 2009).

To consider the second decision problem of mate search, we will assume that the outcome of the first decision process is that all assessed cues have been collapsed into a single criterion value of mate quality (for more on how the information search about each individual prospect can be folded into the sequential search for new, better prospects, see Saad, Eba, and Sejean 2009). What heuristic can be used to guide mate search through a sequence of potential mates with different mate quality values?

Mate search in most developed cultures is two-sided, which means that individuals searching for a mate are being sought by others at the same time, and choice must therefore be mutual. Two people aiming to marry must both decide on this together, and if either decides to pass up the current potential partner now, they are unlikely to be able to return to that person in the future. Moreover, the searchers typically begin their hunt for a marriage partner with great uncertainty as to whom they are likely to be able to entice – that is, their value in the mating market. These challenges of mutual search can be solved by the searchers learning about themselves – specifically, their own relative position within their pool of fellow mate-seekers, in terms of the same single dimension of overall quality that we are assuming the searcher also computes for all potential mates in decision step one above. They can then use this self-knowledge to determine how high they should aim their search aspirations, with an adaptive strategy being to aim for others as mates who have a similar quality level (Kalick and Hamilton 1986). (A second kind of self-knowledge involves knowing one’s mating-relevant features, which can represent local qualities and preferences, such as immunities to

local diseases, cultural preferences for family size, religion, and language. In the next section, we demonstrate a model of mate choice based on features like these.)

Using a quality-based assessment, one way to learn one's relative ranking is to use the assessments that others make about oneself as a cue about one's own mate value, given the assumption that others can assess our mate quality more objectively than we can ourselves. Following this model, during an initial "adolescent" dating and learning phase every time an expression of romantic interest is received from a member of the opposite sex one could raise one's self-appraisal and consequently one's aspiration level for mate search, and lower both after every rejection. This also fits with intuitions about how romantic successes and failures can induce self-esteem to go up and down, which in turn can affect how high or low people aim in their next romantic endeavors (Kavanagh, Robins, and Ellis 2010). In more detail, this aspiration-adjustment heuristic could start all individuals with an initial aspiration level of 50, which corresponds to assuming oneself to be just average. Then, during the adolescent learning period, for every proposal from someone more attractive than one's current aspiration level, raise the aspiration level to be partway to the other's attractiveness value. Any proposals from someone less attractive than one's aspiration level are to be expected, and so should not lead to any change in self-assessment. Just the reverse happens for rejections: for every rejection from someone below one's current aspiration level, lower the aspiration level toward the other's attractiveness, but for the expected rejections from more attractive individuals, leave one's aspiration level where it is. As each individual's aspirations change over the course of the adolescence period, they also influence the learning of everyone else's aspiration levels via the combined effect of the proposals and rejections made, so the aspirations of the population as a whole improve – that is, come closer to reflecting the individual's own mate value, and hence where they can reasonable expect to aim their courtship effort – over time in a bootstrapping kind of way.

When this simple heuristic, which takes into account the decisions made by others, is tested in simulations of artificial "mate seekers" interacting with each other, the individuals who end up in "married" pairs are well matched to each other in terms of mate quality (Todd and Miller 1999). In other simulations, modifications of this type of aspiration-adjusting mutual search rule have come even closer to matching population-level trends in human mating behavior, including correlations between partner characteristics and sex-ratio effects (Simão and Todd 2003). The fact that self-reported individual self-esteem goes up and down with dating success or failure (Kenrick, Groth, Trost, and Sadalla 1993; Kirkpatrick and Ellis 2001; Kavanagh, Robins, and Ellis 2010) points to the psychological plausibility of this aspiration-adjustment heuristic.

To look for other sources of evidence that people are using such a heuristic in mate search, we can turn to data collected at the population level. Demographers have long

puzzled over a common skewed bell-shaped pattern in the distribution of ages at which people first get married (Coale 1971); this same pattern is reproduced in the simulations of marrying heuristic-searching agents when the time it takes for couples to be formed is recorded (Todd, Billari, and Simão 2005). But more useful tests come from direct and fine-grained methods for assessing whether individual people actually use something like this type of heuristic as they search through a sequence of mates. In this regard, we have studied mate search via decisions about potential mates made within a speed-dating context, where the rate of encounters is greatly enhanced (Beckage, Todd, Penke, and Asendorpf 2009). Speed dating is an organized event in which several men and women seeking dates sequentially meet and assess each other within the span of an evening, talking to each potential partner for about five minutes and then deciding whether they would like to meet that person again for an extended date. Researchers have begun using speed dating as a source of data about the mate choices that people actually make, not just what they say they would make (Kurzban and Weeden 2005; Todd et al. 2007; Finkel and Eastwick 2008; Lenton and Francesconi 2010). By gathering data about the mate quality cues and preferences that speed-daters had, as well as the offers and rejections that they made and received as they met a sequence of potential mates, Beckage and colleagues (2009) were able to determine how well different search heuristics accounted for the pattern of offers that each individual made. They found that the aspiration-adjusting heuristic described above that took into account the perceived interest of previously encountered speed-daters predicted more of the offers than either a one-sided search rule that looked only at mate quality (without feedback) or a fixed aspiration level.

3.2 Modeling feature-based mate choice with computer simulations

The perspective of ecological rationality indicates that heuristics will fit well to some environments and not to others, producing better or worse decisions depending on the extent of that fit. We have tested the sensitivity of mate search heuristics to aspects of the environment in which they are used. The results indicate that the behaviors produced by these heuristics are sensitive to some environmental features that vary across cultures. In particular, how long these heuristics search before making the decision to pursue a particular mate can differ in different environments, and this search time can in turn have a direct impact on the timing of children. For instance, the aspiration-adjusting search mechanism of Simão and Todd (2003) predicts a decrease in time to find a partner (and hence presumably in reproducing) as the sex ratio varies from 50:50 in a society. Even more predictions about the effects of societal context can

be made with a heuristic model that captures patterns of both marriage and divorce, as we now explain in more detail using a feature-based assessment model.

The agent-based Marriage and Divorce Annealing Model (MADAM – Hills and Todd 2008) captures the features and variability of the available human demographic data on length and timing of relationships. The model is based on a ubiquitous heuristic for animal foraging behavior called area-restricted search, here applied to the search task of individuals seeking high-quality relationships (with quality measured by how well two individuals match on a set of features). With area-restricted search, animals first restrict search to locations where they have the highest expectations, and only later relax these expectations – and look elsewhere – when restricted search becomes unfruitful. The search heuristic of MADAM operates like area-restricted search in that it starts with a high threshold for how similar a mate should be in order to pursue him/her (i.e., searching in a restricted local “similarity” area initially) and then relaxes its threshold over time if no mate has yet been found (i.e., allowing for marriage to occur later in life with individuals who are less and less similar to the searcher). Divorce occurs when a married individual meets another mutually interested individual who is a better match than their current partner. Similarity is determined in terms of the number of shared traits that two individuals have – for instance, the number of books, bands, and movies they like in common, or other aspects of cultural or biological individuality. The operation of the model serves to demonstrate that marriage and divorce processes can be explained as outcomes of a non-competitive heuristic mate search process involving selection for similarity in traits or preferences. The search is noncompetitive in the sense that individuals hope to find a best relationship determined by idiosyncratic preferences and traits that are shared with their partner. This is different from other models that assume a more competitive search based on population-wide common preferences: for example, where objective mate values are assigned to each individual and males compete for the agreed-upon best females (Miller and Todd 1998).

The MADAM model begins by generating 100 simulated males and 100 females. Each individual is assigned their trait identity of k traits, randomly chosen without replacement from the range 1 through N , where N is the number of possible traits to choose from in the population. Each individual’s threshold or satisfice level, j , for matching another individual and thus marrying them, is initially set to k . Each individual is also assigned a relaxation rate sampled from a normal distribution. In year one of model time, each male and each female randomly encounter x members of the opposite sex – these are assumed to be the yearly number of encounters that are of sufficient seriousness to reveal underlying trait similarities. When two unmarried individuals meet, if they match on j or more traits they get married and then fix their satisfice level, j , at the level of their current match. At the end of the year, all unmarried

individuals relax their satisfaction level according to their relaxation rate. In the next year, all individuals meet as in prior years, but only unmarried individuals marry as in prior years. Married individuals who meet new partners (married or unmarried) that exceed their present satisfaction level and for whom they are also acceptable matches (so that both parties agree to a new marriage) then divorce their old partners and marry their new partners, resetting their satisfaction level to that of the new match (i.e., to how many features they and their new partner share in common). The divorced-but-not-remarried individual leaves their satisfaction level at that of the prior marriage, but relaxes it each successive year if no new partners are found.

Our results show that MADAM can qualitatively capture the observed demographic patterns for marriage and divorce, maintaining a relationship between them that is also quantitatively realistic. MADAM offers several specific hypotheses about the influence of individual-level decision mechanisms on current international trends in marriage and divorce. One of the predictions of the model is that population centers with rising heterogeneity (in terms of traits of individuals) should see increasing age at first marriage, with concomitant delay in reproduction. (This increase in age at first marriage should also be observed when individuals more slowly relax their expectations for degree of matching with a partner, which could occur as a society promulgates beliefs in the search for an ideal partner.) Rising population heterogeneity may be a consequence of modern populations and cultures mixing at a rapid rate, both through international travel and via the internet and other long-distance communication networks. Though this may ultimately lead to a more homogeneous world population, initially it leads to local population heterogeneity. Individuals who encounter one another in day-to-day interactions are less likely to share common traits than they might have 50 years ago, or in the tribal environments more common to our ancestors. MADAM makes a number of further predictions that may be tested in real populations undergoing these types of transitions. For example, where two populations come together rapidly (without changing the romantic encounter rate), then the ensuing increase in heterogeneity will also lead to an increase in the age at first marriage. If the two populations differ markedly in their rates of relaxing expectations, divorce should increase relative to marriage rates. On the other hand, if a population were to become more homogeneous over time – for example, due to changes in political policies that increase homogeneity in education and economic status – it should see earlier ages at first marriage. And again, as already indicated, these changes in age at marriage should be reflected in changes in age at reproduction as well.

3.3 Heuristics for parental investment decisions

Simple heuristics have also been explored for solving another type of fertility-related problem of interest to demographers: the challenge of parental investment, providing appropriate amounts of resources to one's offspring. One type of setting in which such heuristics can be applied is when parents do not have enough resources to give equal amounts to all their offspring simultaneously. How, then, can a parent decide which of several offspring it should give resources to first? Parent birds, for instance, when returning to their nest with a juicy bug, typically face a number of gaping mouths that they must decide between. The parent can use the cues of weight, hunger, age, or fixed position of each chick in the nest when picking which one to feed. As in other reproductive decisions already described, approaches based on traditional notions of rationality would dictate that the parent should assess and combine all of these cues to come up with the best choice (where "best" in this case means the choice that will lead to the greatest growth of the nestlings, which is related to the fitness of the chooser). But because each of these cues provides a full ordering of all the chicks (e.g., one is heaviest, one is next heaviest, and so on), only one cue is necessary to determine which chick to feed next without any ties. Through a series of computer simulations comparing different strategies, Davis and Todd (1999) found that one-cue feeding rules perform significantly better (again in terms of total chick growth) than rules that combine all the available information in an attempt to look forward in time and predict the optimal course of action. This is another way that the simplicity of fast and frugal rules can be advantageous: In situations where repeated decisions must be made (as in feeding and raising offspring), a simple cue-based heuristic that uses only present knowledge can outperform rules that attempt to predict an uncertain future, by avoiding the unpredictable noise that accumulates the further forward one tries to look.

When parents have enough resources to go around, so that all offspring can be provisioned at the same time, another simple rule can be used instead: just divide the current resources available for the children among all of them equally. Because this rule can be seen as instantiating parents' desire to treat all their children fairly, it has been called the equity heuristic by Hertwig, Davis, and Sulloway (2002), though this use of the name "equity" is more akin to what economists usually refer to as "equality": equal division of resources rather than division according to some feature that might make one child be rewarded more than another. Surprisingly, though, parents attempting to fulfill the equity motive of treating all their offspring the same by following this heuristic can fail: while each child will receive the same amount of resources at any given point in time, over their entire childhood the middle-born children will receive substantially less than the first- and last-born children. This happens because the middle-borns are typically always in the household with other children, and so sharing resources with them equally at those points in time, while the first- and last-born will

each have time when they are the sole children in the household and during that period will get all of the parents' investment, leading to a higher sum overall for them. Hertwig and colleagues found that the equity heuristic provides a parsimonious account for a number of empirical parental-investment data patterns supporting this counterintuitive outcome; however, Faurie, Russell, and Lummaa (2009) argued that the middle-born disadvantage may apply only to male children.

3.4 Modeling mating decisions in the wild

Increasing our understanding of the decision making involved in fertility-related behaviors benefits from the multiple research approaches outlined above: theoretical analysis of proposed decision heuristics, modeling of broad demographic trends in mate choice through agent-based models such as MADAM, testing of various sequential search strategies through speeded-up forms of real mate search such as speed-dating, and analyzing the emergent effects of heuristics for provisioning offspring. However, the best tests of what decision mechanisms people are using in their mate search and choices during their lifetime can be made by actually observing those processes over an extended period of time. By assessing the mate choice decisions of many individuals over years of their mate-seeking phases of life, we can test hypotheses concerning the sequential nature of mate choice decisions, the role of feedback in search, and the temporal extent of relationships and their impact on future mate search decisions.

We have recently begun a project working toward this goal, modeling the sequential and temporal aspects of mate search as well as the potential health-related impacts of those decisions in an at-risk population of young women for which extensive longitudinal data has already been collected. The goal is to model the decision strategies guiding these women's choices about whether to have sex with specific partners, which partners they choose to have sex with, and what type of contraceptive protection is used if any. All of these choices have direct impact on fertility and the potential for pregnancy, as well as reproductive health outcomes such as sexually transmitted infections (STI). Contemporary research has begun to understand the romantic and sexual nature of the relationships of adolescents and young adults (e.g., Tanner, Hensel, and Fortenberry 2010), but the cognitive decision processes and factors that lead to the decision to have unprotected sex with a given partner are still unclear. The decision is certainly made in part based on the characteristics of the person being considered as a mate – how attractive is he, how smart, how funny, how kind, how well off – and how those features match up with the desired features in the young woman's template of an ideal mate. But as indicated by the sequential search heuristics already described, the decision will also be influenced by the relationships she has had before – if past

relationships have been successful she could search for a similar new partner or perhaps one of an even higher standard, but if past relationships have failed she may aim lower the next time and settle for a new partner who meets reduced aspirations. Thus, to get a complete picture of the mate choice process, we need to know not only what characteristics are being sought and found in the partners that people have sex with, but also what was being sought previously, and whether the previous searches were successful or unsuccessful in terms of the sexual relationship.

As a source of such data, we are working with the Young Women's Project (YWP; Fortenberry et al. 2002), an extensive longitudinal study that tracked the manifestations of mate choice decisions in terms of relationships, desires, and sexual behaviors of a set of women across a considerable span of time. The YWP started in 1999 and enrolled 387 adolescent women who provided quarterly interviews, quarterly self-collected vaginal swabs for STI diagnosis, annual self-completed questionnaires, and two 84-day (12-week) periods of daily diaries each year. Questionnaire data includes the traits desired in an ideal partner, while data provided in quarterly interviews and in daily diaries can be either woman-specific (e.g., Did you drink alcohol today? How irritable did you feel today?) or partner-specific (e.g., How attentive to you is person X in general? How did person X make you feel today?). This allows linking partner characteristics to the woman's preferred ideal traits and to specific sexual and contraceptive behaviors with that partner, as well as STI or pregnancy associated with that partnership. The average duration of participation in the YWP was 2.7 years, with a range of 1–8 years. Subjects have provided more than 4,406 quarterly interviews (average 12 interviews/subject), 1,446 annual questionnaires, and more than 180,000 person-days of diary information. At any given quarterly visit, about 35% of subjects reported condom use at the most recent coitus and 60% reported use of some form of hormonal contraception. Overall, about 29% of the subjects had at least one pregnancy. This suggests sufficient variation in the condom use, contraceptive use, and pregnancy to allow exploration of the decision processes leading to unprotected sex and its consequences in this population.

By modeling the sexual decisions in this dataset with different heuristic mechanisms, tuned to different pieces of the available information, we can see which heuristics best account for the actual fertility-related choices made by the women in the study. For instance, with the longitudinal data available we can study how ideal preferences change over an extended period of time, and how they are affected by the experiences with particular potential mates during that time – do successful relationships with desirable mates (according to the woman's own ideals) lead to an increase in aspirations for future mates (rising ideals), as the aspiration-adjustment heuristics suggest? Do women who switch directly from one partner to another (without a period of being single in between) choose the second partner as being closer to her

ideal than the first (as the “trading up” mechanism of MADAM would suggest), and if so, does that result in a longer, more successful second relationship than the first? Or do such switches instead happen more because the first relationship fails, resulting in a change of the woman’s ideal preferences? And are there any influences on these mate choices stemming from the woman’s conception probability in her monthly cycle at the time the choice is made, as suggested by several earlier studies (e.g., Haselton and Gangestad 2006)?

In addition to uncovering the common heuristics being used by the young women for sequential and simultaneous mate search and mate assessment, we will also look for individual differences in the extent of search before (and after) mate choice, in terms of both the number of relationships and the degree of matching to the individual woman’s desired traits. These differences in cognitive search behaviors have considerable public (and individual) health consequences, with regard to both early pregnancies and the spread of STIs – more search and more sexual contacts in shorter amounts of time increase the chance of encountering an infected partner and subsequently spreading the infection to others. The early identification before extensive mate search of individuals who are likely to use high-risk mate search styles is important for efforts to reduce the likelihood of adolescents acquiring an STI (Tu et al. 2009).

We think it may be possible to identify individuals who are likely to engage in more extensive and risky mate search if the individual differences in mate search behavior are correlated with differences in other types of behavior that we can measure. Previous research has shown that individuals who search more in one domain – for instance, in a spatial experimental task – also search more in another domain – such as seeking information in memory (Hills, Todd, and Goldstone 2008). We are looking for a similar correlation between such easily measured cognitive tasks and the social mate search behavior of individuals. Such a finding would not only increase our understanding of the underlying heuristic processes guiding people’s search in different domains, but could also inform interventions targeted at individuals who may be at particular risk of mate search strategies associated with increased risk of pregnancy or STI, allowing them to be deployed earlier, when they are able to provide greater benefit.

4. Open research questions

By studying the ecological rationality of simple heuristics for fertility-related decisions and how they are matched to particular decision environments, we are gaining insights into the mate search and choice mechanisms individuals use, how these are influenced by cultural environment differences in factors such as sex ratios and age-at-marriage norms, and how they are influenced by individual differences in experience during the lifetime with different partners. By building simulations of what happens when many individuals use these heuristics over time to make their mate choices and fertility decisions, we can also understand better how demographic patterns at the population level emerge from choices made by interacting men and women. These simulations also help us to further hone our models of the individual decision heuristics, when we find mismatches between the predictions of the simulations and the behavior observed in the real world (Todd, Billari, and Simão 2005).

Further questions remain to be explored, though, about the more direct links between mate search and choice behavior and the fertility consequences of that behavior. How does the choice of a particular mate affect the decision to have children with that mate (or with others)? If a chosen mate is closer to one's ideal partner, does that lead to a tendency to have more children with that mate? Some evidence suggests that a woman's conception probability increases during sex with masculine and dominant men (Puts, Welling, Burriss, and Dawood 2012), which could point to such a relationship between mate choice and fertility. Does a longer mate search process (holding age constant) positively or negatively affect the number of children had in a relationship? The strategies used to decide whether and when to have children need more investigation as well: is it ever a carefully considered rational cost/benefit decision, as some economists would suggest (e.g., Becker 1991), or is it more often a heuristic (as well as emotional) decision ultimately based on only a few factors, such as "Never let the children outnumber the parents"?

The unique contributions of the ecological rationality perspective to fertility research include specifying the cognitive information-processing mechanisms that guide what is going on in the heads of individuals as they make reproductive decisions, and elucidating how those processes fit with the structures of available information in the environment. This fit may be a good one, using heuristics that match the challenges and informational affordances of the environment, and so lead to good decisions about when to have children and how to provision them. Or it may be a bad fit, using heuristics that are better matched to some environment other than the one in which individuals find themselves. These mismatches could arise for various reasons: they may be evolutionary in origin if the modern environment differs from the ancestral one in which the decision strategies evolved, or cultural in origin if the strategies were

learned or shaped in one cultural setting and then transferred for use in another (as when an individual moves to a new country). Across many fertility-related domains we find evidence for decision mechanisms that expand and change with experience and feedback from the local environment, which should serve to increase the match between the two, but these processes will not prevent mismatch if the environment changes too much or if the change comes too late in the individual's life. This mind–environment fit is important, for without it decisions may be made that result in children being born who cannot be adequately cared for, opportunities being missed for having healthy children, or life-shortening STIs being contracted. To be able to adequately assess this degree of fit and its implications for people's lives, we need to study all of these aspects of fertility-related choices: the cognitive decision mechanisms that individuals are using, the structure of the environment in which they live and make their reproductive decisions, and the mesh between the two.

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