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# Can Strategic Ignorance Explain the Evolution of Love?

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## Abstract

People’s devotion to, and love for, their romantic partners poses an evolutionary puzzle: Why is it better to stop your search for other partners once you enter a serious relationship when you could continue to search for somebody better? A recent formal model based on “strategic ignorance” suggests that such behavior can be adaptive and favored by natural selection, so long as you can signal your unwillingness to “look” for other potential mates to your current partner. Here, we re-examine this conclusion with a more detailed model designed to capture specific features of romantic relationships. We find, surprisingly, that devotion does not typically evolve in our model: Selection favors agents who choose to “look” while in relationships and who allow their partners to do the same. Non-looking is only expected to evolve if there is an extremely large cost associated with being left by your partner. Our results therefore raise questions about the role of strategic ignorance in explaining the evolution of love.

*Keywords:* Game theory; Cooperation; Strategic ignorance; Love; Computational social science

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## 1. Introduction

Why do people typically stop searching for other potential partners once they enter a serious romantic relationship? Put differently, why do people fall devotedly in love with one person, even when a “better” partner may come along?

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On the assumption that people ultimately evolved to pursue their self-interest, it seems maladaptive to stop your search for an ideal partner just because you are currently engaged in a relationship. For example, suppose that Fred is looking for a partner among a population of individuals who vary in how ideal they are. Since it is costly for Fred to spend time searching, he might choose to eventually settle down with somebody who is a seven-out-of-ten match for him rather than wait—perhaps forever—for the perfect ten to come along. Indeed, an expansive and complex literature has explored the mathematics of such problems in great detail (Chow, Moriguti, Robbins, & Samuels, 1964; Ferguson, 1989; Freeman, 1983).

But suppose that instead of having to settle down with that one partner, Fred could have his cake and eat it too by entering the non-ideal relationship while continuing to look for better options at the same time. It is clear that Fred is better off doing this than committing to the non-ideal partner, since he can immediately leave his current partner as soon as somebody better becomes available. In other words, it seems better for Fred to never fall in love with one person unless this person is the absolute best he is going to get.

Of course, in the real world, this line of reasoning seems misguided. For the most part, people in relationships demand that their partners be faithful and not seek out other potential mates. And although people sometimes try to get away with checking out who else is available while they are in a relationship, it is clear that this is risky and could result in getting left by one's partner if caught. Moreover, there is a straightforward rationale for why relationships work this way: It is costly to invest in a relationship, so it makes sense to try to protect that investment by demanding that your partner does not seek out other possible partners, for whom they could leave you.

The economist Robert Frank famously presented this rationale to explain why people fall in love (Frank, 1988). Although love seems like an “irrational” emotion to have if you are trying to maximize your time spent with good-quality partners, it might actually serve as an honest signal to your partner that you are so uncontrollably infatuated with them that you would never want to seek anybody else out. If your partner only wants to be with you in the first place if they can ensure that you are unlikely to leave them, it might then be in your self-interest to fall in love with them—so long as being in a long-term relationship with them is better than being alone.

This logic seems compelling, but so does the opposite argument that falling in love is disadvantageous because it limits people's ability to search for the best possible partner. Formal models, rather than verbal theories, allow us to more precisely weigh the value of signaling that you are in love against the freedom of being able to search for other partners while in a relationship. To that end, here we introduce a formal model of partner choice to examine the evolution of romantic commitment.

## **2. Cooperate without looking**

Hoffman and colleagues were the first to provide a formal model exploring whether love (and other psychological phenomena that bind one to act without considering

temptation) could be in one's adaptive self-interest (Hilbe, Hoffman, & Nowak, 2015; Hoffman, Yoeli, & Nowak, 2015). They developed a clever paradigm called the "envelope game" to examine the value of strategic ignorance in cooperative interactions. In this game, two players are engaged in a potential long-term relationship, but in each round Player 1 has the opportunity to "defect" on Player 2. If Player 1 defects, Player 2 incurs a cost and Player 1 receives a "temptation" payoff. The value of this temptation payoff varies across rounds, and it is sealed inside a metaphorical envelope. Critically, Player 1 can choose to either look in the envelope and decide whether to defect based on the information he has learned about the temptation to defect, or he can forgo looking inside the envelope and decide whether to defect without knowing the temptation. Both Player 1's decision of whether to look and whether to defect are visible to Player 2, and hence, Player 2 can decide whether to continue the relationship based on whether her partner looked at the temptation inside of the envelope and whether he defected.

The envelope game was developed as an abstract model representing a wide range of social interactions involving strategic ignorance. For the purpose of romantic commitment, our current focus, the temptation to defect can be conceptualized as the temptation to leave your partner for a new partner who may yield greater benefits to you. The decision to look inside the envelope, then, is meant to capture the commitment property of love (or related phenomena) described earlier—that love makes you not check out other potential partners (and signals this commitment to your current partner). By constructing this model, Hoffman and colleagues could ask whether it is ever in your self-interest to forgo looking inside the envelope ("falling in love") in order to reap the benefits of a long-term relationship with your current partner.

These authors found that the success of this strategy depends on the nature of both your current relationship and the distribution of temptations that could arise. If the expected payoffs from remaining in your current relationship are lower than the average temptation to defect, you are better off simply looking in the envelope and deciding whether to defect based on the temptation size (and allowing your current relationship to end if your partner demands non-looking). In other words, in this case, hopping from short-term to short-term relationship pays off more than falling "blindly" in love with one person. Conversely, if the temptation to defect *never* exceeds the expected long-term benefits of staying with your current partner, your partner need not care whether you look in the envelope because she knows you will not be tempted to defect. Put simply, when your partner knows that she is the best you can get, there is no need for you to signal that you are blindly in love with her.

When, then, is love adaptive—that is, when is it in your self-interest not to look in the envelope and try to maintain your long-term partnership? This "cooperate without looking" (CWOL) strategy arises in conditions that lie between the two extremes just described. If the temptation to defect *occasionally* exceeds the expected long-term benefits of staying with your current partner, but does not exceed these expected benefits *on average*, it is best for Player 1 to forgo opening the envelope (and for Player 2 to demand that Player 1 not look inside).

By thinking through the mathematical logic of the model, we can get an intuition for these conditions required for CWOL to be an equilibrium. First, note that if you look inside the envelope, your partner will leave you because she does not want to be with somebody who even occasionally defects. So it only makes sense for you to look inside the envelope if you believe that the temptation inside will be greater than the value of sticking with your current partner. And while this will occasionally be the case, the condition we just laid out implies that you will typically suffer greater costs by looking in the envelope and losing your current partner than you will by forgoing the temptation. Thus, in the parameter regime in which the temptation to defect is occasionally high but on average lower than the payoff of sticking with your current partner, it is adaptive to engage in CWOL in service of maintaining this long-term partnership. This yields the conditions under which the model predicts that people should fall in love, as there is both an incentive to signal that you are not interested in seeking other options and an expected payoff from staying with your current partner that outweighs the expected payoff of leaving them for somebody else.

### **3. Simplifications made by the envelope game**

The mathematical formulation of the puzzle of love offers much more than a verbal theory. At the level of verbal theory, we had no way to assess whether (or when) it was in one's interest to forgo the temptation to seek out other partners in service for maintaining one's current relationship or to simply jump around from one short-term relationship to another. The CWOL model shows that both of these strategies can be optimal depending on the setting, and it delineates the conditions under which each is successful.

Another advantage of formalization is that it allows direct assessment of the impact of theoretical assumptions and comparisons between different models. While the envelope game—which is particularly attractive because of its simplicity and abstractness—is one way to model romantic commitment, it is not the only way. Here, we explore the implications of certain assumptions that the Hoffman et al. model makes about the nature of romance. To reiterate, we take one of this model's strengths to be its abstractness: By framing the phenomenon of love in such a general light, the model is able to help explain a number of social situations beyond romance, such as friendship, altruism, and even the philosophy of deontology. Thus, the choice to use the highly general envelope game to represent love was not an act of laziness, but a careful modeling choice in service of elegantly explaining many puzzles at once. Nevertheless, modelers must always tradeoff abstraction and realism, and as a model becomes more abstract, it also must inevitably make certain simplifying assumptions that may turn out to fundamentally affect the model's conclusions.

We focus on two simplifying assumptions the envelope game makes about romance. First, the two players in the envelope game make asymmetric and asynchronous decisions: Only Player 1 is tempted to look into the envelope and to defect, and only Player 2 chooses whether or not to continue the relationship (after finding out Player 1's

decisions). In real-world romance, however, both parties are typically tempted to seek outside options, and either can choose to terminate the relationship. While the quality of outside options for the two parties may vary, the temptation still exists for both individuals. Second, the temptation to defect itself is also left abstract. In the envelope game, this temptation is simply a payoff (sampled from a fixed distribution) that is immediately available to the player to “grab” from the envelope. But, in reality, this temptation usually involves a third party, with whom the first party could have a relationship. Thus, somebody who is tempted to leave their romantic partner faces risks of being rejected or quickly abandoned by their new partner. Moreover, the likelihood that these events will occur may depend on each party’s willingness to seek out other relationships while in their current one.

To investigate the impact of these simplifying assumptions, we consider what happens when *both* players in the envelope game can be tempted to look and thereby find out what other partners are available, and when players differ in their desirability as partners (as a result, the available temptations for each player differ). Thus, both agents simultaneously commit to being lookers or non-lookers and to allowing looking or demanding non-looking.

We additionally make two other changes to the formalism of the original model. First, to add realism, we suppose that the value of the temptation in the envelope varies continuously (though this turns out not to affect the outcomes). Second, we focus on a one-shot version of the game (cf. Hilbe et al., 2015) rather than including a “continuation probability” within each pairing. Finally, after analyzing this model, we also present an extension that considers the implications of introducing costs to abandoning or being abandoned by one’s partner.

## 4. The present model

### 4.1. Setup

Two agents (Player 1 and Player 2) face the prospect of entering a relationship. The agents have quality  $q_1$  and  $q_2$ , respectively, ranging from 0 to 1, which indexes their desirability as a partner. Thus, Player 1 receives a payoff of  $q_2$  from partnering with Player 2 in the future, and Player 2 receives  $q_1$ . As in the envelope game, though, each agent also faces a temptation to “look” for other partners before committing to the current relationship. The magnitude of this temptation varies from 0 to 1, representing the quality of other potential interested partners. Critically, the expected value of this temptation for a given player is proportional to his or her own quality. In other words, more desirable agents are more likely to be sought out by desirable agents, thus leading to greater temptation.

Specifically, the temptation for each player is sampled from a beta distribution with parameters  $\alpha = 1$  for both players, and  $\beta = q_1^{-1}$  for Player 1 and  $\beta = q_2^{-1}$  for Player 2. The  $\beta$  parameter controls the positive skewness of the distribution, such that higher

quality agents will sample from temptation distributions that are relatively less skewed in favor of yielding low-quality samples (see Fig. 1 for sample distributions). A player with quality  $q$  will have an expected temptation value of  $q/(1 + q)$ . In the limit as  $q$  approaches 1, the temptation distribution is a uniform distribution, where a high value (e.g., 0.9) is just as likely to be sampled as a low value (e.g., 0.1), and the expected value of “looking in the envelope” is 0.5. (We use the beta distribution to represent the temptation on the premise that there is a uniform distribution of qualities of potential partners, such that the distribution of partners willing to partner with you goes from heavily skewed toward low quality if you are yourself low quality, to uniform if you are maximum quality, in which case all possible partners would want to partner with you.)

Each player in the game chooses whether to be a “looker” (assessing the temptation payoff that is available by checking out possible alternative partners) or a “non-looker” (forgoing the temptation). Each player also decides to accept potential partners who look or not. Payoffs of each agent are then determined by a two-stage decision. First, the potential partners decide if they are compatible, based on whether each allows the other to be a looker. If one player chooses to be a looker and the other does not allow looking, the players do not enter a relationship because they are not compatible, and each must look for a new partner. Since in this situation each player must find a relationship from scratch, we call this the “alone” payoff  $A$ , which is equal to the expectation of the beta distribution  $q/(1 + q)$ .<sup>1</sup> Otherwise, the pair enters a relationship.

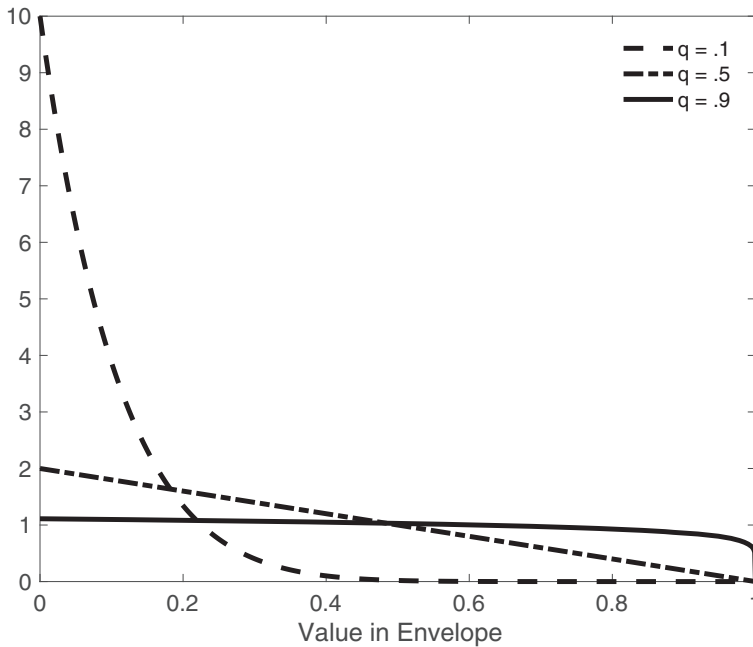


Fig. 1. Probability density functions of temptations in “envelope” for different quality players. Temptations are sampled from a beta distribution with  $\alpha = 1$  and  $\beta = 1/q$ , leading to greater positive skewness for lower quality players.

Once a pair enters a relationship, though, it is not guaranteed that they will stay in the relationship for the long term. Those who enter a relationship and are lookers first get to sample from their temptation distribution and find out whether there are other potential long-term partners of higher quality than that of their current partner. If so, they leave their current partner and enter a long-term relationship with somebody of the quality that they sampled. Payoffs are then calculated solely based on the quality of each player's long-term partner.

Specifically, if both players commit to non-looking, then their payoffs will simply be the quality of their initial partners,  $q_2$  and  $q_1$  for Players 1 and 2, respectively (because neither has the opportunity to see if there is somebody else better). In contrast, payoffs in situations in which at least one player chooses to look and the other player allows it are more complicated. In such cases, each player's future relationship status is uncertain, since one of the lookers may leave the current relationship for somebody else if the temptation that this player draws when searching for a new partner is larger than the quality of the current partner. For example, suppose Player 1 is a looker, and Player 2 is a non-looker who allows looking. Player 2 has committed to staying with Player 1, and hence, Player 1 knows he can at least get a payoff of  $q_2$  by sticking with Player 2. But because he is a looker, he also takes a sample from the dating pool and may leave his partner for this temptation, should it exceed  $q_2$ . Meanwhile, because Player 2 does not look, she will either get  $q_1$  if her partner stays with her or nothing if her partner leaves.<sup>2</sup> Borrowing terminology from the Prisoner's Dilemma, we denote Player 1's payoff in this situation as  $T$  (since he is *tempted* to leave his partner) and Player 2's payoff as  $S$  (since she risks being *suckered* by Player 1's defection).

The magnitude of  $T$  and  $S$  will depend on Player 1's probability of finding someone better than Player 2, which will itself depend on both Player 2's quality  $q_2$  and Player 1's distribution of temptations. Specifically, we integrate over the probability density function of Player 1's beta distribution  $f_1(x; 1, q_1^{-1})$  to get the probability that Player 1 stays (integral from 0 to  $q_2$ ) or leaves (integral from  $q_2$  to 1) Player 2. In the case that he leaves Player 2, we can integrate over the *product* of  $x$  and  $f_1(x; 1, q_1^{-1})$  to get the expected value of Player 1's future partner. Putting this altogether and simplifying the resulting equation, we are left with

$$T = q_2 \int_0^{q_2} f_1(x; 1, q_1^{-1}) dx + \int_{q_2}^1 x f_1(x; 1, q_1^{-1}) dx$$

Meanwhile, the  $S$  payoff for Player 2 is simply the probability that Player 1 stays with Player 2, multiplied by  $q_1$ :

$$S = q_1 \int_0^{q_2} f_1(x; 1, q_1^{-1}) dx$$

What about the case in which *both* players choose to look and allow the other to do the same? To calculate Player 1's payoff  $B$ , we need to consider three possibilities: (1) Player 1 samples a temptation greater than  $q_2$ ; (2) Player 1 samples a temptation less than

$q_2$ , but Player 2 samples a temptation greater than  $q_1$ ; and (3) each player samples a temptation less than  $q_2$  and  $q_1$ , respectively. In situation (1), it does not matter what temptation Player 2 finds, since Player 1 will leave her for his temptation payoff. In Situation (2), Player 1 is stuck with whatever temptation less than  $q_2$  he finds, since Player 2 will leave him. In Situation (3), neither player wants to leave his or her partner, and each player receives  $q_2$  and  $q_1$ , respectively. To get the expected value, we simply take the sum of these three expected values, weighted by their probabilities, which simplifies to

$$B = q_2 \int_0^{q_2} f_1(x; 1, q_1^{-1}) dx \int_0^{q_1} f_2(x; 1, q_2^{-1}) dx + \int_0^{q_2} x f_1(x; 1, q_1^{-1}) dx \int_{q_1}^1 f_2(x; 1, q_2^{-1}) dx + \int_{q_2}^1 x f_1(x; 1, q_1^{-1}) dx$$

The following inequalities hold for all values of  $q_1$  and  $q_2$ :  $B > A$ ,  $B > S$ , and  $T > B$ . To see why, first consider how  $B$  relates to  $A$ . The player's alone payoff  $A$  is simply the expectation of the value of the temptation (i.e., his or her beta distribution). In contrast, a player who is in a relationship in which he and his partner can look gets to take a sample from the temptation distribution, just as the alone player does, but also gets to stay in his relationship in the case that he samples a temptation lower than  $q_2$  and his partner samples a temptation lower than  $q_1$ . Since  $q_2$  is greater than what he would get from the envelope in this case, his payoff from  $B$  is strictly greater than  $A$ . Put simply, by already being in a relationship (albeit one in which his partner may leave him), Player 1 has some insurance, which the alone player does not have, against the bad outcome of sampling a low-quality potential new partner. Note that this logic holds not only for a beta distribution, but for virtually all possible temptation distributions. So long as there is some probability that Player 1's partner will not leave him and some probability that Player 1 will sample a partner with lower quality than Player 2's quality, it is better for Player 1 to enter the relationship with Player 2 as a looker than not.

It is also easy to see why it is necessarily the case that  $B > S$  and  $T > B$ . The "sucker" simply gets nothing if her partner leaves her, whereas she gets the temptation value if she can look. Since the temptation value will always be greater than 0, it is always better to be in a mutual looking relationship than in a relationship in which only your partner looks. Conversely, a looker is always best off in a situation in which his partner does *not* look, since he will then be guaranteed at least the  $q_2$  payoff on the next round. If his partner can look, though, he may end up with a payoff less than  $q_2$  if his partner samples a temptation value greater than  $q_1$ . Thus, the temptation payoff  $T$  will always exceed  $B$  (and, by transitivity,  $S$ ).

#### 4.2. Results

We are now prepared to consider how each player's strategy—look (L) or no look (N) and allow looking (A) or don't allow looking (D)—will influence his or her payoff. These payoffs



are presented in Table 1. We use the subscripts 1 and 2 to indicate each player's respective payoffs. (Note that what we define as  $T$  and  $B$  above is  $T_1$  and  $B_1$ , and what we define as  $S$  is  $S_2$ , but  $T_2$ ,  $B_2$ , and  $S_1$  are calculated in the same way, with  $q_1$  and  $q_2$  flipped.)

To analyze the predicted evolutionary dynamics of the model, we consider whether a given strategy pairing is Robust Against Indirect Invasions (RAII; Van Veelen, 2012). A pairing is subject to indirect invasion if at least one party can neutrally deviate to another strategy and get the same payoff, and this neutral deviation gives the other party an advantageous deviation. Moreover, once the other party deviates, the first party does not have an incentive to deviate back to the original strategy.

From this definition, we see that (LA, LA) is always RAI, since either party reduces their payoff by unilaterally switching to a different strategy given that  $B > A$  and  $B > S$  (as described above). That is, (LA, LA) is a strict Nash equilibrium. Indeed, the logic laid out above suggests that (LA, LA) is a strict Nash for *any* possible temptation distributions, so long as there is some nonzero probability that each player stays in his or her relationship.

What about (ND, ND), which most closely resembles the key CWOL equilibrium from the envelope game? Table 1 shows that (ND, ND) is *not* RAI, no matter the values of  $q_1$  and  $q_2$ . This is because ND is neutral with NA (when neither party looks, whether one demands looking or not is payoff-irrelevant), which allows drift to carry (ND, ND) to (ND, NA) or (NA, ND); and once one player switches to NA, the other player has an incentive to look (both LA and LD outperform ND when playing against NA). Thus, indirect invasion of (ND, ND) dooms romantic commitment in our models. The same logic holds for all other pairings besides (LA, LA). As can be seen in Table 1, all of these strategies are neutral with respect to some other strategy that will ultimately incentivize both players to adopt and allow looking.

How do the results of our model compare with those of the original envelope game? Just as (ND, ND) is not RAI in our model, it is also the case that in the original model, the CWOL equilibrium in which Player 1 chooses to CWOL and Player 2 only maintains a relationship with a player who does not look inside the envelope (and cooperates) is not RAI. If Player 1 does not look inside the envelope, whether or not Player 2 demands non-looking is payoff-irrelevant; but if Player 2 stops demanding looking, Player 1 has an incentive to look, which in turn motivates Player 2 to never maintain a relationship with

Table 1  
Payoff table for the model

Player 1	Player 2			
	LA	LD	NA	ND
LA (Look + Allow)	$B_1, B_2^a$	$A_1, A_2$	$T_1, S_2$	$A_1, A_2$
LD (Look + Don't Allow)	$A_1, A_2$	$A_1, A_2$	$T_1, S_2$	$A_1, A_2$
NA (No Look + Allow)	$S_1, T_2$	$S_1, T_2$	$q_2, q_1$	$q_2, q_1$
ND (No Look + Don't Allow)	$A_1, A_2$	$A_1, A_2$	$q_2, q_1$	$q_2, q_1$

<sup>a</sup>Robust against indirect invasion.

Player 1, making it always in Player 1's self-interest to take the temptation listed in the envelope. Thus, in the original envelope game, CWOL could collapse into an equilibrium in which Player 1 was effectively forced to take what is in the envelope (similar to our payoff A) because Player 2 would not enter a relationship with him.

Crucially, however, the CWOL equilibrium still evolved in the envelope game, at least to some extent, because *no* strategy pairing in the envelope game was RAI: If Player 1 always takes the temptation, then Player 2's choice of whether or not to demand non-looking is payoff-irrelevant; and once neutral drift leads Player 2 to demand non-looking, then Player 1 once again has an incentive to not look (and to cooperate). As a result, in the envelope game, indirect invasion leads back to CWOL in the same way that it leads away from CWOL.

Herein lies the critical difference between the dynamics of the envelope game and our model: In contrast to the (Player 1 defects, Player 2 terminates relationship) pairing in the envelope game, in our setup (LA, LA) *is* RAI. And as a result, only (LA, LA) should evolve.

To confirm that evolution does indeed exclusively select for the (LA, LA) pairing, we consider the stochastic evolutionary dynamics of a population of  $N$  agents evolving via the Moran process. This dynamic can describe either genetic evolution or social learning. We perform exact numerical calculations in the "limit of low mutation" by calculating the steady-state distribution from a Markov chain (Fudenberg & Imhof, 2006). Because this calculation assumes a single population of agents interacting, we model a given agent's strategy as a pairing, where each agent in the population plays in both the Player 1 and Player 2 roles and receives fitness proportional to the average payoff of playing in each of these roles. (Fitness here is defined as  $e^{w\pi}$ , where  $w$  is the intensity of selection and  $\pi$  is the agent's expected payoff from interacting with other agents in the population, as in Bear and Rand [2016].)

Evolutionary outcomes for the full range of  $q_1$  and  $q_2$  values, with  $N = 100$  and  $w = 10$ , are presented in Fig. 2. As shown by the brighter colors, the (LA, LA) pairing is overwhelmingly favored by evolution for just about any pair of qualities, except pairs in which one of the player's quality is exceptionally low, and it is almost guaranteed that one of the lookers would end up leaving his partner. In contrast, the proportion of time that evolution selected the (ND, ND) pairing never exceeded 5% for any combination of quality pairs (not pictured here).

#### 4.3. Costs of abandonment

The above analysis assumes that there are no costs to ending a relationship, beyond the opportunity costs of missing out on a long-term partnership. In the real world, however, there are often significant additional costs to switching or leaving a relationship. For example, if the partners were living together, they would need to rearrange their living situations; and if the partners were married or had children, costly legal settlements involving divorce and childcare could ensue.

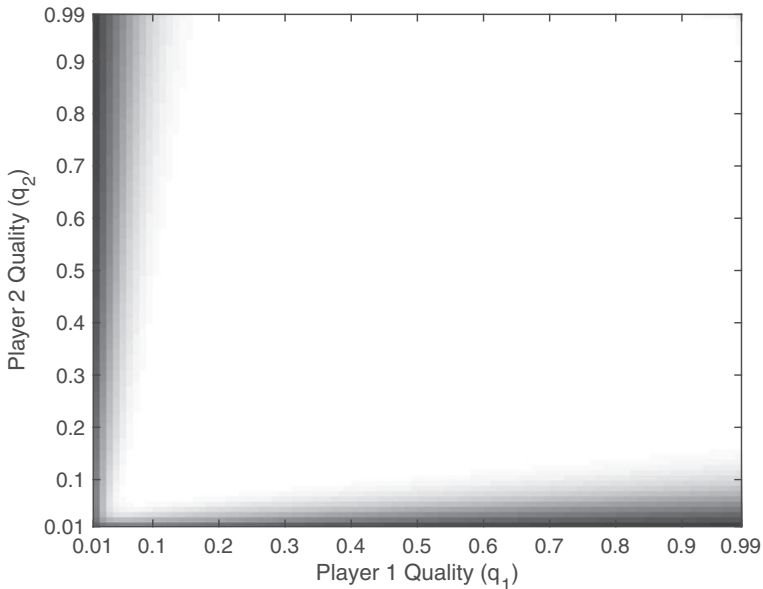


Fig. 2. Probability that the (LA, LA) pairing is selected by evolution as a function of each player's quality. Lighter colors indicate higher probability (white = probability of 1).

These costs will, of course, depend on a lot of different factors (e.g., parental investment [Trivers, 1972]), most of which we do not model here. Nevertheless, we can consider the consequences of imposing generic costs of either abandoning one's current partner or being abandoned by one's current partner.

First, consider the cost of abandoning one's current partner. If a player faces a cost of leaving his current partner in favor of the sampled temptation, this simply imposes an additional constraint on the quality that the potential new partner needs to have in order to justify leaving the current relationship. For example, if Player 1 has just entered a relationship with Player 2, who has quality 0.4, and faces a temptation to leave Player 2 for a partner of quality 0.5, he should only do so if the cost of abandoning Player 1 is  $< 0.1$  (since  $0.5 > 0.4 + \text{the abandonment cost}$ ). Thus, although including such a cost in the model will change the exact conditions under which it is rational to leave a relationship, it will not qualitatively affect the  $B > A$ ,  $B > S$ , and  $T > B$  inequalities, so long as there are still *some* situations in which it is worthwhile to abandon one's partner. Given this, (LA, LA) remains the only equilibrium that is RAI and can be selected by evolution.

What about a cost to being abandoned? Critically, such a cost *could* undermine (LA, LA)'s status as a strict Nash if this prospect of rejection outweighs the costs of being alone. Suppose that  $B_1^*$  is the expected payoff of Player 1, who is a looker, entering a relationship with Player 2, who is also a looker, when there is some cost  $c$  to being abandoned. (For simplicity, assume there is not a cost to abandoning one's partner of the sort described above.) Then, (LA, LA) is no longer a strict Nash when  $B_1^* \leq A_1$ . If we define rejection as a situation in which your partner leaves you, but you do not want to leave

your partner, then rejection for Player 1 occurs with probability  $p_{r1}$ , where

$$p_{r1} = \int_0^{q_2} f_1(x; 1, q_1^{-1}) dx \int_{q_1}^1 f_2(x; 1, q_2^{-1}) dx$$

which yields

$$B_1^* = B_1 - cp_{r1}$$

Thus, (LA, LA) is no longer a strict Nash when

$$c \geq (A_1 - B_1)/p_{r1}$$

Fig. 3 shows this minimum rejection cost at which (LA, LA) is no longer Nash (and, in turn, RAI) for different Player 1 and Player 2 qualities. To contextualize the magnitude of this cost, we plot the ratio of this cost to  $A_1$ . Thus, we show how much worse rejection must be relative to Player 1's expected payoff when he is alone in order for Player 1 to prefer being alone to entering a relationship with Player 2 when both players are lookers. In some regions of this space, one player also prefers being alone to entering a non-looking relationship with the other ( $A_2 > q_1$  or  $A_1 > q_2$ ). However, as depicted, there is also a region in which (ND, ND) is an equilibrium and, therefore, Player 1 and Player 2 both would want to commit to not looking for the other—that is, in this region where (ND, ND) is an equilibrium, we would expect the evolution of non-looking. In general, in this region, the rejection cost needs to be quite high (around 10 to 100 times the alone payoff) for (LA, LA) to no longer be an equilibrium. Thus, while there may be some unique circumstances in which rejection is costly enough to justify demanding non-looking, our model suggests that such cases are rare.

## 5. Discussion

We built a game-theoretic model of romantic partner choice in which agents could signal to their current partner that they were “in love” enough to stop searching for other partners, or they could continuously search for better partners even while in a relationship. In contrast to previous work, we found that evolution almost never favors agents who commit to non-looking in service of signaling their commitment. Instead, a strategy of “look and allow your partner to look” was the only strict Nash equilibrium in the game and the only strategy that was unable to be invaded by mutant strategies in a dynamic population, assuming the costs of being rejected by a “looking” partner were not exceptionally large.

Our analysis highlights the importance of seemingly minor assumptions in formal modeling. The present model closely resembles the “envelope game” from Hoffman et al. (Hilbe et al., 2015; Hoffman et al., 2015), in which one player is tempted to look inside

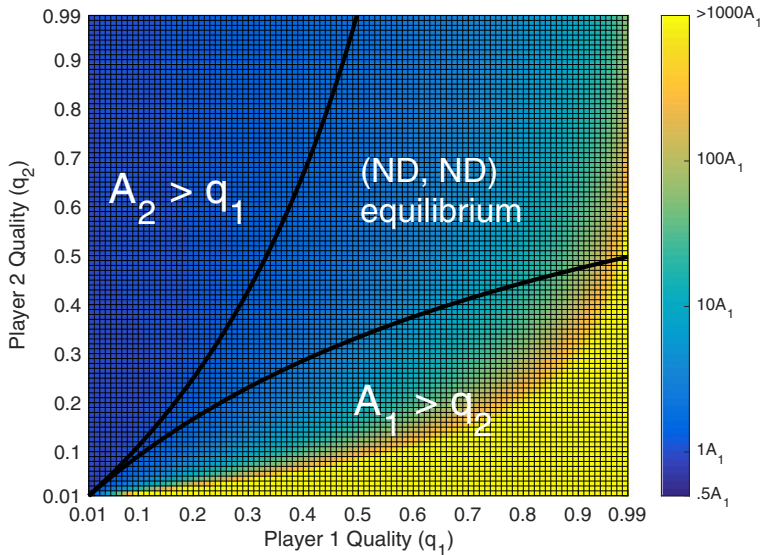


Fig. 3. The minimum ratio of rejection cost  $c$  to Player 1's alone payoff  $A_1$  for (LA, LA) to no longer be Nash. Also depicted are regions in which (ND, ND) is and is not Nash.

an envelope and defect on his current partner, but he can choose to instead CWOL inside the envelope. Under certain conditions in which the other player will only accept a partner who does not look inside the envelope, it can be optimal for the first player to CWOL. Similarly, our model supposes that one player is tempted to look inside the envelope, and the other player can condition her behavior on whether the first player looks. But we further suppose—as seems to more closely resemble real life—that the second player can be tempted as well. We find that giving both players some temptation (even if these temptations are not of the same magnitude) and an ability to condition his or her behavior on whether the other player looks at the temptation undermines the CWOL equilibrium. In particular, our model gives rise to a pairing that cannot exist in the original envelope game, in which *both* players look and allow looking, and it is this pairing that is robust to indirect invasion (in contrast to the always defect equilibrium in prior work).

As discussed earlier, these results underscore the importance of trading off generality and specificity in formal modeling. The original CWOL model offers a highly abstract and elegant framework for demystifying many puzzling social behaviors beyond the romantic domain—something that is of, no doubt, tremendous value. Nevertheless, in maintaining this level of generality, such a model needs to gloss over particular details. One of these details—the asymmetry of temptation—proved critical to the success of a non-looking equilibrium.

One might reasonably ask why, in the real world, we seem to observe people falling in love and committing to their partners (Gonzaga, Keltner, Londahl, & Smith, 2001) if game theory suggests that this is not an optimal strategy. A “look and allow looking”

approach seems to be far rarer than a strategy that demands one's partner end their search while in a serious relationship. Furthermore, some empirical work suggests that more principled "non-lookers" are trusted more than calculating types in non-romantic domains (Critcher, Inbar, & Pizarro, 2013; Everett, Pizarro, & Crockett, 2016; Jordan, Hoffman, Nowak, & Rand, 2016; Sacco, Brown, Lustgraaf, & Hugenberg, 2017).

There are several reasons why this might be the case. For one thing, the present model is by no means the final word on whether committing to a single partner can be an adaptive strategy. Indeed, many theories have been put forth to explain why humans and other animals are monogamous (Kleiman, 1977; Wittenberger & Tilson, 1980), which depend on factors from which we have mostly abstracted away, such as parental investment (Trivers, 1972) and sex differences (Symons, 1980). Furthermore, as we have discussed, the present model still makes many simplifying assumptions, which may turn out to affect what conclusions we can draw. Of particular note is the possibility that people could be *conditional* lookers—choosing to look when their partner allows it, but otherwise wisely forgoing this temptation. Some preliminary work of ours suggests that adding a strategy of this sort does indeed influence the evolutionary dynamics observed in favor of non-looking. Still, it is not clear that this modification engenders the kind of stable non-looking behavior observed in the real world. Moreover, other changes to the present model could favor lookers over non-lookers. For example, we (and the original envelope game) suppose that the magnitude of the temptation in the envelope does not depend on whether somebody allows or does not allow looking. But it seems plausible that people who allow looking will be able to attract more desirable partners, insofar as looking affords potential partners the freedom to leave a relatively undesirable partner after a short period of time.

Alternatively, strategic ignorance may not be the primary or only explanation for real-world non-looking and related emotions like love. For example, if an equilibrium in which people blindly commit to their partners is better for the group than one in which people hop around from one relationship to the next, group selection or related processes might favor norms that enforce emotional commitment (Henrich, 2004). In turn, those who violate these norms could face punishment from bystanders or have their reputation tarnished in such a way that it is more difficult for them to find partners in the future (cf. Boyd & Mathew, 2015; Henrich & Boyd, 2001). This kind of story seems to accord with real-world anecdotes. For instance, somebody in a long-term relationship who is found to be flirting with other potential romantic partners at a party is likely to face criticism and may even be branded a cheater. Moreover, such an equilibrium could be compatible with individual-level selection if third parties are incentivized to punish for signaling benefits (Jordan, Hoffman, Bloom, & Rand, 2016; Jordan & Rand, 2017).

There may even be partly non-social reasons for people to fall in love with their partners. Although certain features of love are essentially social in nature, people can also become infatuated with inanimate objects (Lastovicka & Sirianni, 2011) or even their own ideas. This kind of "love" may have spilled over from the social domain, or it may have a domain-general, non-signaling explanation. For example, an obsessional devotion to something like a house may help motivate its quick pursuit in situations in which the opportunity to buy could be suddenly lost, or it may signal the optimal point for someone

to transition from an exploration to an exploitation mindset, which could be studied empirically (cf. Navarro, Newell, & Schulze, 2016).

In short, there is still much work to be done in understanding why people seem to develop an apparently irrational devotion to their romantic partners. Is it in one's best interest to obsessively focus on a single individual at the expense of potentially better options? Although the ubiquity of this behavior in the real world demands an explanation, the present model suggests that we are still far from a satisfying explanation for why people fall in love.

## Notes

1. As in the envelope game, we make the simplifying assumption that the expected partner quality of an agent does not depend on the agent's strategy (looking vs. non-looking and allowing vs. not allowing looking). Of course, in the real world, this need not be the case (e.g., somebody who allows looking may be more desirable because you do not have to commit to an exclusive relationship with them). We comment on this point further in the Discussion.
2. One might wonder why the payoff of a "sucker" who is left by her current partner is 0 rather than  $A$ . We assume this because the non-looker has committed to a relationship in this case and may not be immediately aware that her partner has left her for somebody else. Thus, she does not have the chance to search for a new partner in the current round—whereas she clearly does have the chance to do this if she never entered a relationship in the first place.

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