

Survival of the luckiest

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Opposite dynamics are behind natural selection and sexual selection. When considering natural and sexual selection separately, the fittest individuals survive. However, when these processes interact, luck often determines the survivor. As a result, chance has a greater impact on evolution.

In episode 3 of Netflix's *Night on Earth*, it is a full-moon night in a Central American rainforest, and two male frogs *Physalaemus pustulosus* try to impress a demanding female. As their acoustic mating calls are not enough to impress her, the vocal sacs of one of the males begin to inflate and deflate like a pulsating balloon, creating ripples on the surface of the water [1]. He is on his way to winning the competition and mate. This contest exemplifies sexual selection in action. However, the propagating ripples unintentionally also serve as a target in the water echolocated by a bat *Trachops cirrhosus*. This circumstance is an example of natural selection in action. The impending winner of sexual selection has died as a result of natural selection, and the prospective runner-up frog is the one who survives and ends up reproducing. His success depended on chance.

Of course, in this scenario, survival is still determined by natural selection. The frog with the trait of weaker vocal sacs is relatively unfit with respect to attracting the female in sexual selection, but relatively fit with respect to avoiding predation in natural selection. The survivor is the fortunate individual not solely because of natural selection, but because of the interplay between natural and sexual selection, which have different dynamics, namely negative and positive feedback, which we shall discuss next.

Any organism that engages in costly signaling is susceptible to predation as a consequence of emitting the signal. This is true whether the signal is a warning signal, a courtship signal, or any other signal that may attract a predator or parasite's attention. However, we would like to draw attention to the fact that both sexual and natural selection act simultaneously in the preceding example. "The survival of the fittest" is a phrase coined by Herbert Spencer that is not part of standard evolutionary research but does influence public understanding of evolution. Taking it at face value, we can see that "survival of the fittest" only makes sense if we overlook the relationship between natural selection and sexual selection. If we do not, the "survival of the luckiest" best reflects the condition of every living individual.

Charles Darwin did not develop his theory of natural selection simultaneously with sexual selection. The sight of a peacock used to make Darwin sick because his bright feathers did not appear to have any clear survival value. He could not explain it with his

theory of evolution by natural selection. So, he felt compelled to further devise his theory of sexual selection to explain peacock plumage [2]. Darwin derived his concept of sexual selection from his general theory of descent with modification, which he established in *The Descent of Man* in 1871. *On the Origin of Species* was first published in 1859.

Consider another perennial drama on the theater stage of evolution. The antlers of the elk *Cervus canadensis* are primarily used as weapons in combat between males for access to females, not against predators. The use of antlers as a form of defense against predators is secondary. By means of runaway selection, the larger the antlers, the better. R.A. Fisher proposed runaway selection in the early twentieth century. He contended that the attractiveness of a male elk's antlers, for example, leads to a positive feedback loop in which individuals with the trait are favoured and so more likely to reproduce. This can result in the evolution of increasingly extreme variants of the trait over time. In other words, this situation results in an arms race. However, large antlers render an elk more vulnerable to the wolf *Canis lupus* attacks in areas with a high density of trees. In most cases, a trait that evolved to help an individual compete better in battles against conspecifics is a disadvantage to the species as a whole [3]. The species would benefit from smaller antlers on each individual. Regardless, having smaller antlers would not be in one's best interests. Individual and group interests clash. Economists refer to this as the collective action problem [4]. Therefore, we propose that we frame sexual selection as a collective action problem.

As previously stated, R.A. Fisher discovered that sexual selection has a positive feedback mechanism in terms of dynamics. As in an arms race, there is an amplification of an initial disturbance in the presence of positive feedback [5]. Natural selection, on the other hand, has a negative feedback mechanism in which a system responds in the opposite direction to a disturbance. A mutation that improves one hawk's eyesight, for example, is likely to spread through natural selection, making it suitable for the group of hawks as a species. The individual's and the group's interests are aligned [3]. To clarify, the evolution of advantageous traits such as improved eyesight in a hawk initially provides a distinct survival benefit to the individual, facilitating superior hunting and evasion capabilities. However, the spread of this mutation through natural selection signifies not just an individual advantage but a collective enhancement for the species. Over time, as these traits become prevalent, they contribute to the species' overall fitness and adaptability in their environment. While individual benefits may seem to diverge from group interests initially, they ultimately converge, promoting the success and sustainability of the species as a whole. Obviously, negative feedback is not exclusive to natural selection, as a mutation that enhances a male's secondary sexual trait is also likely to spread through a population.

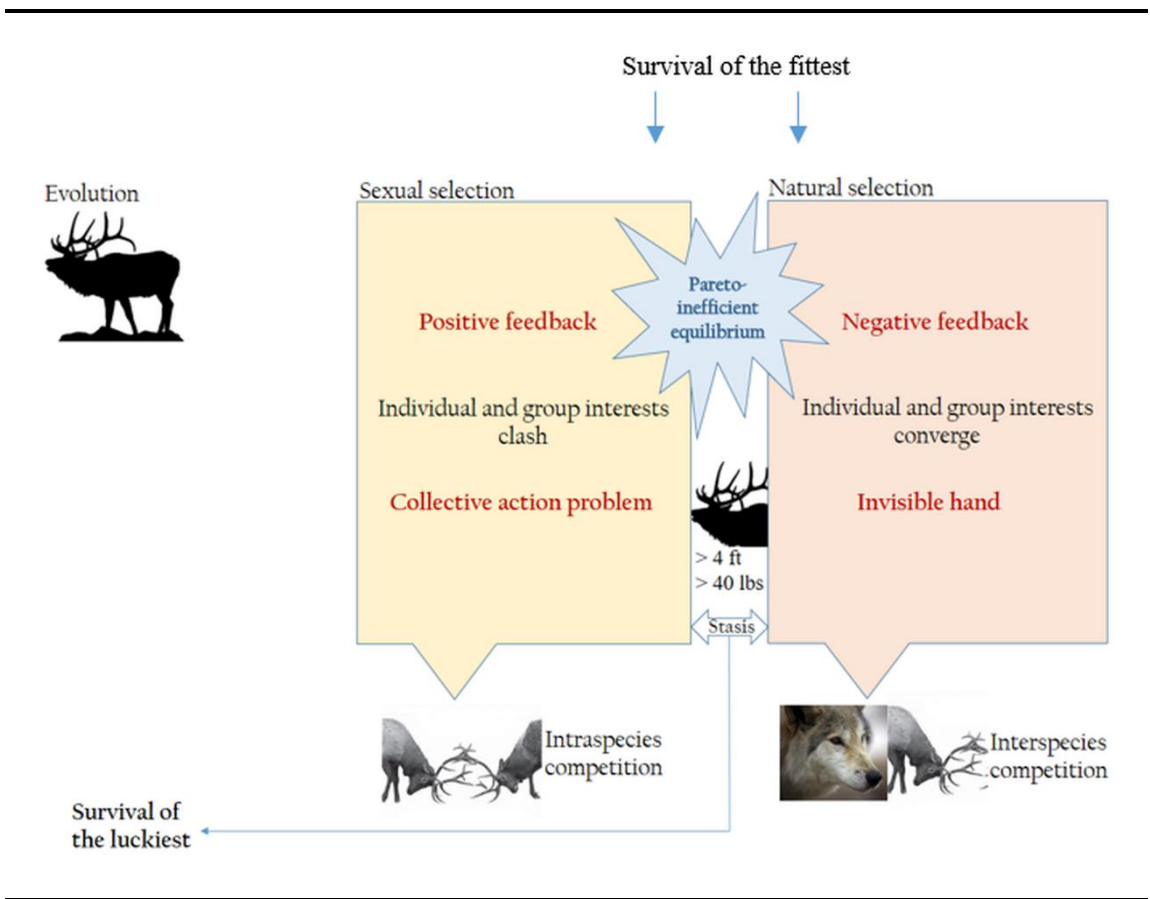
In their metaphor of the "invisible hand," economists preferentially prioritize negative feedback [5]. They exploit this property to demonstrate that markets function well, extending to all forms of collective behavior [4]. Goods and services markets have negative feedback, whereas financial markets may have positive feedback. For example, when the price of an iPhone rises, the number of people who want one decreases. However, if the price of Apple stocks rises, the demand for them may rise as well!

We argue that positive feedback occurs in *intraspecies* competition and negative feedback occurs in *interspecies* competition. For example, a typical *Cervus canadensis*

antler is more than 4 feet in diameter and weighs slightly over 40 pounds. In interspecies competition, one elk with antlers larger than this equilibrium value has become or will become wolf food. In intraspecies competition, an elk with smaller antlers is less likely to mate. This equilibrium is called stasis or steady state. It is Pareto-inefficient, which means that trimming every elk's antlers in the same proportion will improve the position of all elk. Therefore, surviving individuals' antler size is not optimal in this sense. Of course, evolutionary processes do not generally produce optimum conditions, despite the fact that biologists frequently employ optimality models. (See the infographic.)

In arms races, individual incentives lead to waste. Peacocks with exaggerated tails result from competition for females with positive feedback. Peahens prefer a flamboyant tail because this signals a healthy immune system and progeny. However, peacocks with oversize tails are more visible to predators. To see that those overly large tails mean waste to the group, imagine we chop off 2 inches of the tail from all group members. Every male's relative position remains unchanged as a result of this procedure. The experiment reveals a collective action problem, in which the invisible hand fails. It also reveals that one individual's interest in the intraspecies competition clashes with the group's interest.

In human affairs, collective action problems abound. For example, a hockey player prefers to play without a helmet because they gain a competitive advantage by seeing, hearing, and speaking more clearly. However, this increases their chances of being hurt. If players had the option of wearing helmets or not, they all choose not to. If they vote, however, they choose the mandatory helmet for everyone [4].



The collective action problem is ubiquitous and extends to any goal dependent on relative income. Many objectives in life are dependent on relative purchasing power. When you earn more money, you improve your ability to achieve your goals while decreasing the ability of others to achieve the same goals. This may not be the case if the economy as a whole is expanding, but current activities that increase an individual's income impose what economists call negative externalities on others [3]. This fact justifies market intervention because, as John Stuart Mill observed, the only legitimate reason to limit one's freedom is to prevent harm to others.

While we should encourage negative feedback competition in the economy, we should discourage positive feedback competition [3]. We should free the invisible hand under negative feedback dynamics, limiting the market power of monopolies and oligopolies. However, there is a need for regulation in positive feedback dynamics to tame the collective action problem and protect us from the consequences of excessive competition among ourselves. After all, rewards based on relative performance create collective action problems, which leads to market failure. Because rewards are based on rankings, there is no way to assume that individual and collective interests are aligned. In an arms race, no more than half of the contestants can be in the top half [3]. Nevertheless, deterring positive feedback competition may hinder technological progress [6]. Therefore, policymakers must distinguish between the positive feedback that contributes to prosperity and the positive feedback that causes collective action problems.

The existing literature on success weights the role of talent and luck in human affairs and boils down to two formulas: 1) success = talent + luck, and 2) great success = a little bit more talent + a lot of luck [7]. However, disentangling talent from luck is a difficult task. Despite this fair reward problem [8], one point has been established: skill alone cannot explain the top rewards [3] [9]. Furthermore, agent-based models suggest that the most successful individuals are rarely the most talented [10]. This finding challenges the meritocratic paradigm by showing that success is not primarily determined by talent. The models reveal that, while some talent is required for success, average-talented individuals frequently achieve the highest levels of success through luck. Thus, luck plays an important part in achieving success, indicating the need to reexamine how rewards and resources are allocated in society. One implication is that plans based exclusively on merit may neglect the essential role of luck, thereby losing opportunities to encourage individuals who could contribute considerably to innovation and growth if given the chance.

Returning to nature, what role does the lucky one play in evolution? Darwin gave chance a lot of thought, and modern biologists are still thinking along same lines. It has been established that evolution involves 1) adaptations, 2) by-products, and 3) randomness [2]. However, an adaptation responds to a mutation, or randomness that occurs in a single individual. It may give the individual an advantage (or disadvantage) in terms of survival and reproduction. If the mutation is beneficial, it will spread throughout the group and become a species adaptation. However, one implication of what we are showing is that evolution is ultimately just randomness, namely 1) the adaptations that result from successful mutations (randomness), 2) its by-products (second-degree randomness), and 3) mutations (randomness) that do not translate into adaptations.

We conceptualize selection as a dynamic of positive and negative feedback. The concept of selection as dynamics is not foreign to Darwin, who uses the example of domestication (artificial selection) to show how evolution by natural selection is plausible. Domestication dynamics illustrate how a population can be transformed through differential reproduction of its component individuals, and this dynamic can be extended to nature. While a breeder selects among a population of domesticated animals in artificial selection, and thus intentionality is compatible with teleology, natural selection explains adaptation without recourse to teleology. Natural selection was not well received by Darwin's contemporaries because of its rejection of teleology [11]. Darwin himself acknowledges that natural and sexual selection have distinct dynamics. Historically, Darwin added sexual selection later after originally proposing only natural selection, as observed. However, logically and developmentally natural selection comes before sexual selection. This can be demonstrated in species that reproduce only once in their lifetime and then die. This is because the primary objective of these species is to survive long enough to reproduce successfully, as opposed to attracting mates and reproducing repeatedly.

Semelparous species reproduce just once before death, showcasing how natural selection favors strategies that prioritize survival until reproduction over sexual selection's emphasis on mate attraction and competition. Key examples include: Pacific salmon (*Oncorhynchus spp.*), which die after spawning; octopuses (*Octopus vulgaris*), ceasing to eat and dying post-egg-laying; antechinus (*Antechinus stuartii*), with males dying after intense mating; Australian redback (*Latrodectus hasseltii*) and black widow spiders (*Latrodectus mactans*), where males perish soon after mating, the latter noted for females consuming the males; slender opossum (*Marmosops spp.*), a semelparous marsupial from South America, dying after mating; trans-volcanic bunchgrass lizard (*Sceloporus bicanthalis*) in Mexico, with a lifecycle where females die before males; Labord's chameleon (*Furcifer labordi*) from Madagascar, both genders die after the mating and egg-laying period, with a notably short lifespan; sockeye salmon (*Oncorhynchus nerka*), returning to freshwater to spawn, then dying after ceasing to feed.

Notwithstanding, sexual selection is solely based on individual efforts to monopolize the gene pool, and the results may be detrimental to the species as a whole. It may even result in extinction. This is an additional route to extinction, as natural selection can also lead to extinction. Thus, teleology is unnecessary, and maladaptation is possible. While natural selection explains adaptation, sexual selection is compatible with maladaptation [11]. This allows for attitudes like Alfred Russel Wallace's, who rejected sexual selection while accepting natural selection.

According to textbook wisdom, evolution is based on constraints of physical and chemical laws, the two principles of descent and modification (selection), and chance. The synthetic theory of evolution considers evolution as changes in gene frequencies in a population caused by mutation, migration, drift (sampling error in finite populations), and selection. As sexual selection interacts with natural selection, we contend that chance is the most fundamental factor. The luckiest survive while the other factors remain in play. The Netflix example at the beginning shows a sequence of sexual followed by natural selection, but when the males pulsate rather than call, that change is not just a random innovation, but they do it to attract females. Thus, the workings of

sexual selection are in place, despite the fact that the victim of predation is naturally selected against. The runner-up frog's success in sexual selection is random, yet it arises from the combined effects of natural and sexual selection. Although our case does not rule out the other factors, it appears heretical because chance is the ultimate destroyer of any teleological ideas. When operating in automatic mode, our minds are prone to type I errors, detecting patterns where none exist. People seek patterns and refuse to accept randomness [7]. This explains the widespread skepticism among Darwin's teleologically inclined contemporaries that chance plays a significant role in evolution. However, subsequent debate acknowledged the role of chance in evolution, culminating in John Herschel's description of evolution as "the law of the higgledy-piggledy," implying that chance could influence the design of organisms. Beginning in the 1970s, paleobiologists such as David Raup, Stephen Jay Gould, and Thomas Schopf [12, 13] argued that evolution is predominantly stochastic, emphasizing the role of chance events, such as genetic drift or random mutations, in determining the course of evolution. They argued that randomness played a crucial role in evolutionary history, especially during periods of rapid diversification or mass extinctions. Due to the influence of stochastic events, Gould famously argued [14] that if we "replayed the tape of life" from the beginning, we would not necessarily observe the same outcomes each time. This does not imply, however, that natural and sexual selection do not also play a role.

Intraspecies competition in sexual selection causes a collective action problem because the species would benefit if, for example, each peacock's tail were smaller. The peacock's tail is analogous to human positional goods, where satisfaction with consumption is determined by signal ranking rather than absolute quality [3]. Because rewards are based on rankings, there is no way to reconcile individual and group interests. The effects of an individual's position in a hierarchy on others, even if there is no direct interaction or exchange between them, are referred to as positional externalities [3]. Externalities are costs or benefits that accrue to individuals who are not directly involved in a transaction. The fact that externalities are associated with sexual selection has been perceived in the literature because what is advantageous to certain individuals is not always advantageous to the wholes of which they are parts in sexual selection. Sexual conflict is also an example of the tragedy of the commons [15], which occurs when the depletion of a shared resource has a negative impact on individuals who are not involved in the decision-making process or do not benefit from the resource's exploitation. Sexual selection in evolutionary theory is similar to rent-seeking in economic theory [11], in which individuals seek wealth by capturing a larger share of the existing economic pie rather than creating new wealth. While sex seeks "profit," sexual selection seeks rent [11]. Rent-seeking is associated with externalities because it distorts resource allocation and reduces incentives for individuals to internalize the costs of their activities. This can result in inefficient outcomes because resources are diverted to rent-seeking rather than productive activities that generate new wealth. Because sexual selection is ultimately a collective action problem, externalities, whether positional or those resulting from rent-seeking and the tragedy of the commons, should be involved.

Positively frequency-dependent selection occurs when a phenotype's survival and reproductive success increase as it becomes more common, enhancing traits that offer social or mating advantages. For example, a trait viewed as attractive can lead to better mating opportunities, increasing its prevalence. Conversely, negatively frequency-

dependent selection reduces a phenotype's fitness as it grows common. Additionally, the spread of beneficial alleles that gain fitness advantages as more individuals carry them exemplifies this selection, crucial for genetic diversity and influencing evolutionary changes.

Both natural and sexual selection can exhibit positively frequency-dependent dynamics under certain conditions [16]. In the context of natural selection, positively frequency-dependent selection occurs when traits that become more common in the population confer a greater survival advantage. This can happen for various reasons, such as when a particular trait enhances the ability of individuals to exploit resources more efficiently as it becomes more widespread. Another example is the case of aposematism (warning coloration), where predators more easily recognize and avoid prey with common warning signals, increasing the survival rate of those prey individuals.

For sexual selection, positively frequency-dependent selection can occur when certain traits are preferred by mates, and this preference increases as the trait becomes more common. An example is when a particular coloration or behavior in one sex becomes attractive to the opposite sex, and as it becomes more prevalent, individuals possessing this trait have a higher reproductive success. This can lead to a runaway process where the preference for the trait and the trait itself become more pronounced in the population.

In both cases, the key aspect of positively frequency-dependent selection is that the advantage of having a certain trait increases as the frequency of that trait increases within the population. However, it is important to note that the dynamics of frequency-dependent selection can be complex and context-dependent, influenced by environmental conditions, genetic factors, and interactions with other species. While positively frequency-dependent selection can promote the fixation of certain traits, it can also lead to reduced genetic diversity if it drives the population towards homogeneity in those traits.

In a study on male wood tiger moths (*Parasemia plantaginis*), mating success showed positively frequency-dependent selection, with either white or yellow males having higher fitness when prevalent in the population [16]. This led to models exploring polymorphism maintenance despite selection favoring common morphs. By combining mating experiment data with spatial survival differences between morphs, the study reveals a complex balance of natural and sexual selection that supports polymorphism amid migration and predator diversity. Thus, despite positive frequency dependence, spatial variation allows for polymorphism.

It matters to understand how our central claim relates with the notion of positive frequency dependency. We claim that positive and negative feedback occur in intraspecific and interspecific competition, respectively, and that when combined, the luckiest rather than the fittest individual survives and reproduces. We further characterize sexual selection as intraspecific competition and natural selection as interspecific competition. Does the presence of positive frequency dependence in both natural and sexual selection directly contradict our claim? Absolutely not.

Positive frequency-dependence in natural and sexual selection does not exclude the significant role of stochastic events (luck) in evolutionary processes. Our argument is

about the combined effects and outcomes of these mechanisms, rather than their existence in isolation. Our stance focuses on how selection types and evolutionary randomness interact, acknowledging positive frequency dependence's role. It highlights that survival and reproductive success are influenced by both trait prevalence and unpredictable elements such as environmental shifts and mutations. This complexity suggests that occasionally, luck can override pure fitness, affecting the evolutionary direction of species.

In the case of Florida's beach mice (*Peromyscus polionotus*), which have color variations for camouflage, stochastic events like hurricanes can suddenly change their survival odds. Although positive frequency-dependent selection typically favors mice whose coloration blends into their environment, random events altering the landscape or predator dynamics can give previously disadvantaged mice a survival edge. This demonstrates the significant impact of randomness on evolution, even when adaptive traits are usually beneficial, highlighting the dynamic between predictable selection forces and environmental unpredictability.

Evolution is shaped by both positive frequency dependence in natural and sexual selection and stochastic processes, which are not opposing but complementary forces. The interplay between deterministic selection pressures (favoring common traits) and random events (such as genetic drift and environmental changes) creates a complex evolutionary landscape. While frequency-dependent selection may dictate trait prevalence, randomness plays a crucial role in determining survival and reproductive success. Hence, evolutionary success hinges not just on fitness relative to selection pressures but also on the luck of benefiting from chance events. This perspective highlights the intertwined roles of selection and randomness in driving biodiversity.

Assortative mating, driven by sexual selection, can lead to reproductive isolation and speciation under certain conditions [17]. This process may also affect an organism's vulnerability to natural selection, as traits favored for mating success could increase predation risk. Our view that luck can sometimes outweigh fitness in survival aligns with this, suggesting sexual selection may promote traits not always advantageous for natural selection. We further incorporate the role of stochastic factors in this dynamic.

Negative frequency-dependent selection, a key type of balancing selection, promotes genetic diversity by favoring rare variants, helping explain the persistence of genetic polymorphisms within populations despite natural selection and genetic drift [18]. This supports our assertion that luck, alongside the effects of both intra- and interspecific competition, plays a crucial role in survival. Specifically, negative frequency-dependent selection, by favoring rare alleles, illustrates how survival advantages can shift to not just the fittest but also the rarest individuals, reflecting the changing dynamics of selection pressures. This mechanism highlights the complex interplay between deterministic selection and stochastic factors in shaping evolutionary outcomes.

Negative frequency-dependent selection plays a key role in both ecological coexistence and evolutionary dynamics by promoting diversity through the favoring of rarer entities [19]. It differs from other coexistence mechanisms by integrating ecology and evolution to explain biodiversity. This selection process helps balance competition, predation, and cooperation, ensuring the persistence of genetic and species diversity. It creates positive feedback in intraspecific competition by advantaging rarity (similar to sexual selection)

and negative feedback in interspecific competition by disadvantaging commonality (similar to natural selection). This suggests that survival and reproduction are often more influenced by stochastic factors than by direct fitness advantages, as negative frequency-dependent selection adds variability and unpredictability, determining success based on frequency rather than absolute fitness [19].

The evolution of mate choice involves the interaction of genetic factors with pre- and postcopulatory sexual selection mechanisms, such as mate choice, sperm utilization, and sexual conflict, highlighting the need for empirical studies to explore these genetic underpinnings [20]. These mechanisms demonstrate how sexual selection (intraspecific competition) influences traits that may not always offer survival benefits in the face of natural selection (interspecific competition). This concept supports the role of random events in affecting survival and reproduction. The genetic and evolutionary implications of mate choice and sexual conflict emphasize that evolutionary success depends on a complex mix of genetic predispositions, sexual selection pressures, and chance.

One review analyzed mathematical models in sexual selection theory, covering their advantages, limitations, and relevance to evolutionary biology [21]. It explored mate choice evolution through various approaches, including population genetics, quantitative genetics, evolutionary game theory, adaptive dynamics, and individual-based simulations, to understand the intricate relationship between mate preferences, genetics, and sexual selection outcomes. Furthermore, the review linked sexual selection with broader evolutionary themes like speciation and parental care, advocating for models enriched with genetic, behavioral, and demographic specifics for deeper insights. This comprehensive examination supports our claim because evolutionary success relies on a mix of genetic factors, competition, and random events, challenging the notion that fitness alone determines success [21].

Understanding signal evolution requires considering selective pressures for manipulation, honesty, and the ability of receivers to detect signals [22]. Returning to the original Netflix example, consider our frog *Physalaemus pustulosus* and the related *Physalaemus coloradorum* [23] [24]. Both species' females are sensitive to certain sound frequencies, but only *P. pustulosus* males have evolved calls that match this frequency. This suggests that female preference for specific sound frequencies evolved first, leading to an adaptation in *P. pustulosus* males but not in *P. coloradorum* males. As a result, *P. coloradorum* females show a preference for *P. pustulosus* males' calls! [23]. This preference may be due to evolutionary lag (insufficient time for genetic variation) or the opportunity costs of trait changes, such as increased predation risk. Thus, different selective pressures (mate attraction vs. predator avoidance) can lead to diverse evolutionary outcomes. This trade-off is a cornerstone of evolution by natural and sexual selection. Interaction between natural and sexual selection matters.

Mathematical appendix

This appendix expands on four topics: 1) We begin by modeling positive and negative feedback in general; 2) We combine the equations for positive and negative feedback to consider a general system where the output is influenced by both types of feedback, with the goal of demonstrating that the equilibrium point is not optimal and unstable; 3) We develop a mathematical model to illustrate the dynamics of positive and negative

feedback in intraspecies and interspecies competition; and 4) We show how the luck and talent components of success can be modeled.

Positive feedback is the process by which the output of a system reinforces or amplifies the initial input, resulting in an exponential growth or increase in the system's response. A self-reinforcing loop occurs when the output signal is in the same direction as the input signal. The following equation depicts positive feedback:

$$y = gi,$$

where y is the output of the system, g is the amplification factor or gain of the system, and i is the input signal to the system.

Negative feedback is a process whereby the output of a system opposes or counteracts the initial input, resulting in system stabilization or regulation. It occurs when the output signal opposes the input signal, creating a self-regulating loop. Negative feedback can be represented by the following equation:

$$y = g(i - f),$$

where f is the feedback signal, which is a portion of the output signal fed back into the system. In negative feedback systems, the feedback signal functions as a corrective measure, reducing the difference between the input and output and aiding in the maintenance of system balance.

To analyze a system whose output is affected by both positive and negative feedback, we combine the equations for positive and negative feedback as follows:

$$y = g_+i_+ + g_-(i_- - f),$$

where we have two input signals: i_+ represents the input signal for positive feedback and i_- is the input signal for negative feedback. The feedback signal used in the negative feedback loop is f .

Assume now that the system is attempting to reach a point of equilibrium where the output remains constant. In an ideal equilibrium, output should equal zero. Nonetheless, this equilibrium cannot be achieved. To observe this, we must set the output to zero:

$$0 = g_+i_+ + g_-(i_- - f)$$

Solving this equation for f :

$$f = i_- + \frac{g_+}{g_-}i_+.$$

The feedback signal is affected by both the positive and negative input signals, as shown by this equation. The ratio of g_+ to g_- determines the proportional impact of

positive and negative feedback on the feedback signal. If the positive feedback gain g_+ is greater than the negative feedback gain g_- , then the feedback signal will amplify the input signals and may cause the system to deviate from the equilibrium point.

Now let us consider a model for the population dynamics of two competing species, A and B , where positive and negative feedback play a role:

$$\frac{d_{N_A}}{dt} = r_A N_A \left(1 - \frac{N_A + \alpha N_B}{K_A} \right) - m_A N_A$$

and

$$\frac{d_{N_B}}{dt} = r_B N_B \left(1 - \frac{N_B + \beta N_A}{K_B} \right) - m_B N_B,$$

where N_A is the population of species A , N_B is the population of species B , r_A and r_B represent the intrinsic growth rates of species A and B , which are affected by intraspecies competition; K_A and K_B denote the carrying capacities (maximum sustainable populations) for species A and B , and α and β are parameters representing the strength of interspecies competition. A higher value of α implies stronger competition from species B on species A , and a higher value of β implies stronger competition from species A on species B . Finally, m_A and m_B represent the mortality rates for species A and B .

In this model, the first terms on the right-hand side of each equation represent positive feedback. It entails that the population size of each species facilitates its growth. Positive feedback increases the growth rate as the population size increases. The second terms on the right side of each equation represent negative feedback. It indicates that the population size of competing species limits the development of each species. As the population of the competing species increases, the growth rate of the species is negatively impacted.

To analyze the dynamics of this model, numerical simulations or analytical techniques such as stability analysis, phase plane analysis, and bifurcation analysis can be utilized. These analyses will assist in identifying the conditions and parameter ranges under which positive or negative feedback predominates, as well as determining the possible behavioral classes exhibited by the competing species.

Finally, to frame the luck vs. talent problem, consider a geometric Brownian motion:

$$\frac{dS_t}{S_t} = \mu dt + \sigma dW_t,$$

where the percentage change dS_t/S_t of a successful outcome in an infinitesimal time-step dt is the percentage drift μ , which represents the talent component, and the

percentage volatility σ , which tracks the luck component [8]. The term dW_t represents the increment of a Wiener process.

After a time T ,

$$\ln S_t \sim \left(\mu - \frac{\sigma^2}{2} \right) T + x_t \sigma \sqrt{T},$$

where x_t is a random variable with a mean of zero and a variance of one. The term $\mu - \sigma^2/2$ is the cumulative effect of talent, and $x_t \sigma \sqrt{T}$ is the cumulative effect of luck. There exists a time T^* at which both talent and luck contribute equally to the outcome. At times T less than T^* , luck dominates and the process is diffusive or random; at times T greater than T^* , talent dominates and the process is drifting [8].

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