The Evolution of Gender-biased Social Learning

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word count: 7975

Introduction

Every known society employs gender categories to assign responsibilities to its members. Which tasks are assigned to which genders, however, varies substantially cross-culturally (Murdock and Provost 1973). This is puzzling: why would so many societies be attracted to gender as a social category if its function varies significantly?

There is a second, closely related puzzle. Humans have tendency to preferentially imitate the behaviors of people who share their gender. This is known as gender-biased social learning. The puzzle is that gender-biased social learning limits potentially useful sources of information. Why not imitate the most useful behaviors around, regardless of who displays them?

Existing attempts to explain the evolution of either of these phenomena are incomplete. In a recent book, Cailin O'Connor tackles the first puzzle (O'Connor 2019). She employs the tools of evolutionary game theory to show how gender might have emerged as a device for solving certain classes of coordination problems. Some tasks are best completed through a specialized division of labor. But without social roles, it can be difficult to coordinate on the issue of who should perform which tasks. Sexual differences are one salient feature in early human societies that could provide a basis for the division of labor.

Her solution presupposes an answer to the second puzzle. She assumes that agents engage in gender-biased social learning. The assumption is necessary to achieve a high level of coordination in the model. But she offers no explanation of the evolution of gender-biased social learning. Moreover, it seems implausible that gender-biased social learning would emerge in evolutionary time prior to the gendered division of labor.

As for the second puzzle, social learning theorists have suggested gender-bias arose to help learners acquire skills necessary for the gender roles they will be expected to fill (Wood, Kendal, and Flynn 2013). While plausible as an explanation for why gender-biased social learning persists, it does not illuminate the evolutionary origins of the bias. The explanation presupposes early human societies already have robust gender roles that learners need to fit into. It is not clear gender roles could develop and stablize without a social learning bias.

Each explanation presupposes the other. To evolve gender one needs biased social learning. To evolve biased social learning one needs gender. This paper proposes that gender and gender-biased social learning co-evolved. The basic suggestion is that each phenomena can develop incrementally, creating selection pressures that reinforce the other. The paper develops formal agent-based models to demonstrate the validity of this argument.

Understanding how social categories bias social learning can shed light on the cultural processes that generate oppression. A body of modeling work treats oppression as the result of social conventions that lock people in inequitable arrangements (Sankaran 2020; O'Connor 2017; O'Connor and Bruner 2019, 2017; Bruner 2019; Henrich and Boyd 2008; Axtell, Epstein, and Young 2000). These conventions are more likely to emerge in populations that learn in a way biased by social categories. Privileged individuals learn the traits they need to maintain their advantage by imitating those with the same privileges. Oppressed individuals adapt to their oppression by adopting the strategies of other oppressed people.

Section one reviews the empirical and theoretical work on the evolution of gender. The second section turns to social learning-biases. Section three presents the co-evolutionary model. Section four explores the implications of this model for cultural evolutionary accounts of oppression.

1. Gender and the division of labor

A good explanation of the origins of gender is a tall order[1]. There are a number of diverse features that need to be accounted for. This section lays out the central empirical findings that motivate a recent explanatory modeling project.

The gendered division of labor is an ancient social institution. The most conservative estimates suggest humans had established a gendered division of labor beginning with the Upper Paleolithic, or roughly 50,000 years ago (Kuhn and Stiner 2006). It is also ubiquitous across cultures. There is no known human society that lacks the institution.

One particular division of labor is exceptionally widespread: large animal hunting is almost always done by men (Murdock and Provost 1973). In societies that practice large animal hunting, women typically gather starches, vegetables, and other resources. The puzzle about why men hunt is a literature unto itself

[1]Even the very meaning of the word 'gender' is a contested issue. In the context of this paper, gender is a set of social roles and behaviors. One might think of this as the 'structural' understanding of gender. This stands in contrast to the 'phenomenological' understanding of gender - this refers to a set of identities through which people interpret their own experiences. Clearly gender encompasses both dimensions but this paper will only explore the first.

and is not explored in detail here (Hawkes 1990; Bird and Codding 2015). However, research on hunter-gatherer societies can inform the more general problem puzzle about why there are gender roles at all. One general insight from this literature is that divisions of labor are advantageous.

Divisions of labor offer benefits from diversification. Societies that pursue both hunting and gathering can capture a more diverse range of nutrients than societies that only collect the most plentiful resource (Gurven and Hill 2009).

Divisions of labor also offer benefits from specializations. Each task may require the performer to make a long-term investment in a specialized set of skills. Specialized laborers typically produce more resources than generalists. Specialization also constricts the ability for individuals to contribute both types of resources. People who hunt efficiently typically cannot also gather efficiently. They both lack the skills and typically have to travel to distinct areas of the community's territory (Gurven and Hill 2009).

A large variety of tasks are divided by gender. The provisioning of food in hunter-gatherer societies is far from the only division. Consider dancing. There are often two sets of moves, one for each partner. Women typically perform one set and men perform the other. Consider opening doors. When two people approach a door at the same time, there is ambiguity about who should open the door for whom. The convention of men opening the door for women removes the ambiguity. Consider the household division of labor. In mid-20th century America, it was very common for women to perform unpaid domestic labor and for men to participate in the paid labor market. Viewed from a high level of abstraction, these are all the same problems that face the hunter-gatherers: two tasks need to be performed, each requires specialization and society has developed a convention to delegate those tasks.

Finally, there is a great deal of variance in how gendered divisions of labor are implemented. Men are not exclusively hunters. !Kung men and women share responsibilities for hunting and gathering (Bird and Codding 2015). Other tasks admit high cross-cultural variance. For example, weaving nets, planting, and harvesting crops are performed by men, women, or both across cultures (Murdock and Provost 1973). Or, consider how gender norms relating to domestic and market labor have changed rapidly in the last century.

One would like an explanation of gender that can unify all these features. The explanation should be simple enough such that a society with only rudimentary social institutions could develop gendered conventions. It should be robust enough to explain why every society has gender. It should be abstract enough to capture a common core to dancing, door opening, food provisioning, and household tasks. It should be flexible enough to account for cross-cultural variability.

O'Connor has proposed a simple game-theoretic model with just those properties. Each of those activities has the characteristics of a complementary coordination game. Consider the following game:

	A	B
A	(0, 0)	(1, 1)
B	(1, 1)	(0, 0)

The game has two players, a row player and a column player. Each selects their action, either A or B. Selection occurs simultaneously and in ignorance of what action the other player has chosen. They receive a payoff according to what pair of actions they pick. If one player performs A and the other performs B, they each get a payoff of 1. The payoff represents the additional benefits accrued from a division of labor compared to the case where each player performs the same task[2]. In dancing, the payoff represents successfully performing the dance. In the hunter-gatherer case, the payoff represents the diversity of nutrients each player receives when they share the day's provisions.

The game has an interesting structure. Despite the players' mutual interests, there is a good chance they fail to coordinate. Neither player knows which equilibrium the other player will aim for. Even if they agreed on a particular equilibrium, they would still need to figure out who occupies the positions of row player and column player.

This captures a key feature of the type of tasks gender typically regulates - ones where coordination has to be orchestrated without the opportunity for discussion. It would diminish the beauty and grace of dancing if each pair of dancers had to plan out their own choreography anew with each dance. For perfect strangers to dance the waltz together, the choreography needs to be mutually and automatically understood between any two dancers. In provisioning, one needs to decide which skills to specialize in, often long before they meet the person they will share a household or raise a family with.

O'Connor's suggests that societies develop social conventions that utilize the sex of the players to break the informational symmetry. If there is a convention where men always perform A and women always perform B, then there is no uncertainty about who should perform which action.

1.1. Dynamic models

O'Connor develops a formal model to explore the conditions under which these conventions could emerge. The model draws on the tradition of evolutionary game theory. Game theorists understand conventions as behavioral regularities that constitute an equilibrium in repeated coordination problems (O'Connor 2019, 2020; Skyrms 1996). The intuitive idea is that people follow social conventions when deviating from them could not bring them any additional rewards.

[2]It is important to underscore the payoff values represent additional benefits over and above some baseline performance. The outcome of 0 implies players are missing out on something they could have, not that generalists never successfully hunt.

Equilibrium concepts in game theory are well-suited for representing situations where it does not pay to change behaviors.

In evolutionary models, players have the opportunity to improve their strategy over time. The assumption is that players observe what others do and copy more successful strategies[3]. This assumption, success-driven social learning, has a good deal of empirical support (Henrich and McElreath 2003; Henrich 2016; Hoppitt and Laland 2013; Mcelreath et al. 2008). The process is typically modeled by an equation known as the replicator dynamics. The intuition behind this equation is that strategies that are more successful than average will grow in frequency. At some point, the population will converge on some distribution of strategies such that no one could improve their luck by changing. This represents the formation of a convention.

In O'Connor's particular model, there are two sub-populations. The populations represent males and females. Players can interact with anyone. However, social learning only occurs inside of each sub-population. In other words, women learn only from women and men learn only from men. This assumption requires strong gender-biased social learning. Assessing the merit of this assumption is the goal of this paper. For now, it is worth taking gender-biased social learning for granted, if just to see what it offers.

The goal is to evolve a convention in which each sub-population performs one characteristic action whenever it interacts with the other. By exploring a range of evolutionary game models, one can gain an understanding of which conventions a population is likely to settle on through simple processes of cultural evolution. Two iterations of models are important for this paper. In the first model, the population fails to achieve a gendered division of labor. In the second, the population succeeds.

First, imagine players only possess simple, unconditional strategies.

- Always perform A
- Always perform B

O'Connor shows this population will evolve until it achieves a 50-50 split in strategies. This is straightforward. 'Always A' does well when most people are playing 'always B.' If there are a surplus of 'always B' players, then 'always A' will grow until they achieve parity. The same goes for 'always B.' The average payoff for both strategies at equilibrium is 0.5. Half the time agents play against agents with the same strategy and get nothing. The other half the time, they play against agents with complementary strategies and receive a payoff of 1. Sexual difference plays no role in this model. Players of either sex are just as

[3] In general, evolutionary models are not committed to the interpretation that social learning drives selection. Natural selection on genes might perform the role. Here O'Connor assumes social learning is operative because there is good reason to doubt gendered behavior is heavily genetic.

likely to perform either action. This corresponds to the situation where the population has no gendered social conventions.

Second, imagine there is also a larger pool of strategies. In addition to the two unconditional strategies, players can condition their strategy on the basis of the other player's sex. These strategies open the possibility that sexual difference can break the informational symmetry in the coordination game. These are referred to as conditional strategies:

- Perform A when playing against males; B when playing against females.
- Perform B when playing against males; A when playing against females.

The result is that the average payoff increases to 0.75. The population will converge to either one of two states. In the first state, males will always play A against females and females will reciprocate by playing B. When agents play against the opposite sex, they always receive a payoff of one. Internal to each sub-population, they still only coordinate half the time. They do not have sexual differences to break role symmetry, so each sub-population is in a state akin to the first model. In the second state, they simply switch actions; males always play B against females and females play A against males. The other dynamics remain the same in the second state.

The model explains why gender should be ubiquitous. It is an attractive form of social organization that requires only simple cognitive abilities. If players could condition their behavior on the basis of sex, they will. The model also explains why we should expect cross-cultural variation in how tasks are divided up. The conventions that form in these models are arbitrary. The population could wind up with a convention in which males perform action A consistently. But they could just as easily end up with a convention in which males perform B[4].

1.2. The puzzle

The result described above depends on the assumption of gender-biased social learning. The assumption ensures that strategies are assorted by sex. Without it, the players cannot achieve the same level of coordination. Males will imitate successful female behaviors and females will do the reverse, breaking the association between sex and behavior. If sex is no longer predictive of the other player's behavior, it doesn't pay to conditionalize one's strategy on it.

[4]A good question about this account is why cultural selection should not just pick an arbitrary distinguisher. A convention does not need to form around sexual difference to divide up labor. This is a correct read on the consequences of the model. However, there is good reason to think sexual difference is salient as a distinguisher in a way many of traits are not. First, it is something early human populations are already interested in for the sake of reproduction. Second, sexual difference remains largely consistent throughout one's lifetime. For skills that require a long period of training, only stable traits can reliably indicate how people should invest their time. Third, in societies that employ heterosexual kinship structures, it is the one trait that most naturally carves up the reproductive unit's division of labor.

There is good reason to find this model explanatorily dissatisfying. It seems implausible that early humans could engage in gender-biased social learning prior to the development of gender. They would need gender to organize the learning experience. O'Connor acknowledges the difficulty:

> There is a worry here, which is that same-gender imitation, and other mechanisms for enforcing proper-gendered learning, are surely at least in part a response to the existence of gender roles and norms. In other words, while the models assume this sort of learning in order to get gendered division of labor, perhaps that is putting the cart before the horse. (O'Connor 2019)

But she leaves it as a task for future research:

> A full account of how groups manage to get all these features in place at once is beyond this book. (O'Connor 2019)

This paper aims to explain how it is possible to get all the necessary features in place at once.

2. Gender-bias in social learning

In defending the assumption, O'Connor points to a body of experimental literature suggesting that people possess a preference for imitating others who share their gender. While the findings in this literature are experimentally robust, this section argues there is currently no ultimate explanation for why humans should exhibit this bias[5].

In a 1979 study by David Perry and Kay Bussey, children were shown videos of actors playing with toys (Perry and Bussey 1979). The male and female actors had sex-distinctive styles of play. After seeing the videos, the children were released into a room with the same toys and left for observation. The children copied the playing style of the actors who shared their sex substantially more often than they copied the opposite-sex playing style. Perry and Bussey theorized that young children keep track of the frequency of sex-behavior relationships and will code certain behaviors as gendered if the frequency is extreme enough.

While there is a theoretical debate about the cognitive mechanisms that drive preferential imitation, the core finding has held up in subsequent studies (Bussey and Bandura 1984; Shutts, Banaji, and Spelke 2010; Wood, Kendal, and Flynn 2013). A recent paper by Losin and her colleagues found that same-gender imitation activates regions of the brain associated with rewards more strongly than other-gender imitation (Losin et al. 2012). Neuro-imaging results are useful in this context because they show that gender-biased social learning is robust with respect to how we measure it.

[5]Ultimate explanations answer questions about why a trait exists at all. They can be contrasted with proximate explanations which answer questions about how a trait operates.

It is not clear why we should expect gender-biased social learning to evolve, either genetically or culturally. Some proximate explanations have been offered. The proximate explanations are useful if one wants to explain why gender-biased social learning forms or persists in contemporary populations. For example, Bandura has theorized that gender-biased social learning is rewarding because it is encouraged by peers, parents, and teachers as part of the socialization process (Bandura 1977). Children undergo a kind of 2nd-order reinforcement learning that shapes their 1st-order social learning behavior. As a proximate explanation, this seems plausible. But a different genre of explanation is necessary to understand the early evolution of gender. It is not clear why we should expect societies to invest resources in rewarding this kind of learning behavior, absent a well-developed gendered division of labor.

Similarly, Wood, Kendal, and Flynn hypothesize that this learning bias helps children acquire behaviors appropriate for their social role (Wood, Kendal, and Flynn 2013). Taken as an ultimate explanation for the development of this bias, it depends on the assumption there are already preexisting social roles. But if, as O'Connor assumes, social roles are a product of processes involving gender-biased social learning, we are left with an explanatory circle.

One is left with a dissatisfying picture from the existing literature. The explanation of gender roles requires learning bias and the explanation of learning bias requires gender roles. The next section presents a model that demonstrates it is possible for the two phenomena to co-evolve.

3. The model

The model presented in this paper retains most of the features of the model developed by O'Connor. Players still pair randomly to play the coordination game. They have the same menu of four strategies and mimic successful strategies. There are two key differences. First, the model is an *agent-based model* rather than an equation-based model. Second, players have a *learning strategy* that evolves.

Agent-based models are well suited to exploring questions about co-evolution. The key difference between equation-based and agent-based models in evolutionary thinking concerns the grain of representation. In an agent-based model, every individual in the population is represented as a distinct entity (Wilensky and Rand 2015). The equation-based models described above only care about the distribution of strategies. They do not care about who possesses which strategy. Agent-based models are programmed so that players (or agents) follow a series of behavioral algorithms. These algorithms can closely approximate the results derived from replicator dynamic equations (Izquierdo, Izquierdo, and Sandholm, n.d.).

The co-evolutionary model of gender consists of two core algorithms - one for playing and one for learning. Each round, every player executes both actions.

In `play`, each player selects a partner at random. The player receives a payoff depending on whether their strategy compliments their partners. In `learn`, each player selects a new partner. The player compares their own payoff to their partner's and copies their partner's strategy with a probability proportional to the difference. Jointly, `play` and `learn` approximate the replicator dynamics.

The advantage of relying on agent-based models is that they remain convenient as one scales up the complexity of the model (Smaldino 2020). Adding second-order social learning is a relatively simple addition with a few lines of code. Agent-based models are analyzed through simulation techniques rather than analytical ones, making it easy to understand how the new model behaves as complexity increases.

In this model, players have a learning strategy that specifies how they learn. There are three possible learning strategies:

- learn from anyone
- learn from a player of the same sex
- learn from a player of the opposite sex

The `learn` algorithm is modified such that players select a partner consistent with their learning strategy. Learning strategies are themselves subject to a selection process. Learning strategies that are more successful than average should grow. In `learn learning strategy`, players select a random partner (any sex) and determine whether their partner's learning strategy is more successful than their own. If it is, they copy it. Each player possesses a memory of the last m payoffs they received while learning with a given strategy. These memories are used to measure the success of each learning strategy. If a series of large payoffs are associated with one learning style, it's deemed more successful[6].

The `learn learning strategy` algorithm can be interpreted in various ways. The first option is to treat gender-biased learning as the outcome of natural selection on genes. If there was some kind of complex genetic trait that disposed children to imitate same-sex demonstrators, this model could represent its evolution. The second option is to interpret the algorithm as a kind of second-order social learning. People learn how to learn by observing others[7]. Although second-order social learning is an under-explored topic, some empirical evidence suggests that it is prominent in human societies (Mesoudi et al. 2016). A third option is that players determine the best learning strategy through individual trial and error learning. Although this algorithm does not explicitly represent individual learning, theoretical work shows reinforcement learning and social learning generally

[6]The model is programmed in Netlogo. Code for the model can be found at https://github.com/daniel-saunders-phil/dancing-game

[7]This interpretation may seem implausible at first glance. Given that learning is not externally visible, it may be difficult to directly imitate the mechanisms by which others learn. However, consider the case where a teacher directs the students' attention to another exemplary student. If the students respond by trying to imitate the exemplar, they are using a kind of second-order social learning.

drive populations to the same outcomes, such that this model should approximate individual learning outcomes (Börgers and Sarin 1997). Most plausibly, some combination of all three options is at work. Some genes influence learning behavior but those genes are either activated or amplified by first- and second-order learning mechanisms. In theoretical research on the evolution of learning strategies, the standard methodological choice is to remain agnostic about what precise mechanism implements the learning strategy (Hoppitt and Laland 2013). It simply does not matter at the level of representation found in these models. The model is merely committed to the claim that if there is a trait for gender bias in social learning and selection could act on it, then we should expect it to grow in the population.

Suppose a population of 500 players repeated executed `play`, `learn`, and `learn learning strategy` over 600 rounds. m is set to 1, indicating players only remember the most recent payoff associated with each learning strategy. The simulation was repeated 1000 times. The frequency of gender-biased social learning at each point in time for all trials is plotted in figure 1. All trials were driven toward gender-biased social learning. At the same time, the population is establishing a gendered division of labor. The strategic dynamics converge to the one described in section 1.

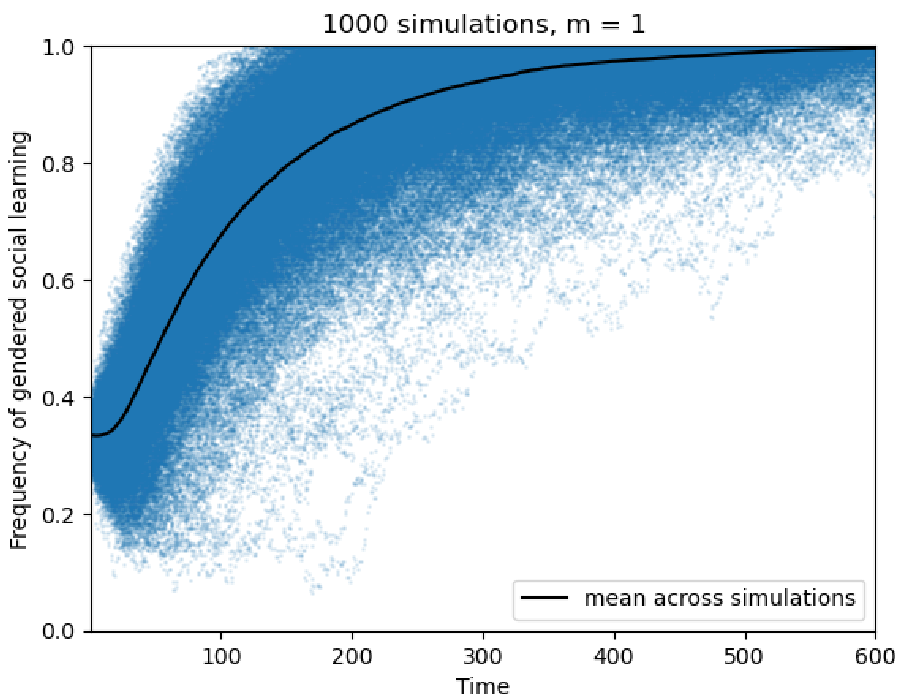

Figure 1: The basic co-evolutionary model

This result suggests that gender-biased social learning is a strong attractor for populations playing coordination games with gendered strategies. If a population could achieve some benefit from allocating strategies by gender, then populations will also be inclined towards gendered social learning. The presence of one encourages the growth of the other, in a mutually reinforcing cycle.

These results also illuminate the pair of puzzles that motivated this paper. In O'Connor's model, she assumes players come ready to utilize gender-biased social learning. These results show that assumption is unnecessary. Gender-biased social learning can evolve endogenously and alongside the gendered division of labor. In the social learning literature, it was unclear how the learning bias could evolve without pre-existing gender roles. These results suggest that the satisfying ultimate explanation is a co-evolutionary one.

3.1. Sensitivity analysis

The agent-based model developed here is little more than a formalization of an argument. A computer model is a great tool for exploring validity - what conclusions follow from a given set of assumptions about human behavior. But the tool is no guarantee of soundness. The evolutionary modeler can make poor assumptions. If the assumptions are unacceptable, the model is not a compelling explanation.

Parameters are assumptions about the constant values that go into the model. In this model, the memory size, the population size, the rate of spontaneous mutations, and the payoffs values are all parameter settings. In a sensitivity analysis, the modeler varies the parameters of the model to see how sensitive the conclusion is to changes in those values. The results provide a sense of the generality of the explanation. If, for example, gender-biased social learning can only evolve under a narrow range of initial conditions, the model would be a poor explanation unless we knew that early human societies possess precisely those initial conditions. Given the kind of radical uncertainty scientists face in their knowledge of the distant past, generality across parameters is indispensable (Currie 2016). We need to know that the same evolutionary logic leads to the same conclusion under a wide range of assumptions.

The general conclusion from this section is that the core insight - gender and gendered learning can co-evolve - is broadly insensitive under many plausible parameter settings. However, parameters can influence the probability, speed, and durability of this outcome.

The primary result used a memory size (m) of 1. Increasing the size of the players' memory allows players to measure which learning strategies tend to be associated with successful interaction over time. These memories are communicated between players when they compare and select their learning strategies. The simulation described above was repeated for players with a memory of the last 10 rounds. Figure two demonstrates introducing larger memories has two effects. First, players converge on gender-biased social learning more quickly.

This is unsurprising. Large memories mean players have more accurate information. Second, larger memories introduce a small probability that gender-biased social learning collapses. 9 trials out of 1000 failed to evolve gender-biased social learning under these conditions, whereas no trials failed in the initial experiment[8].

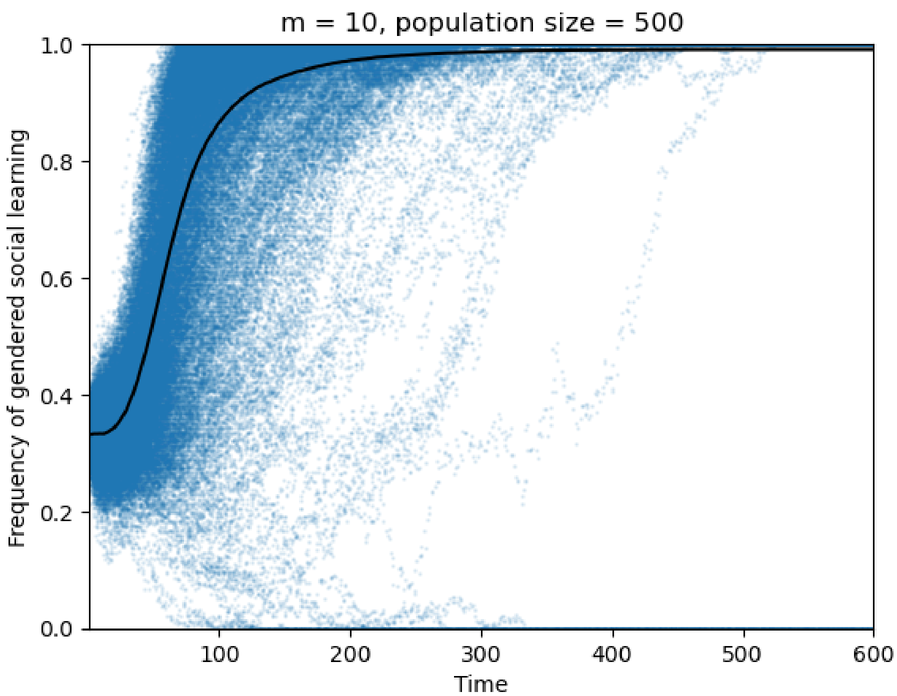

Figure 2: The effect of large memories

The second effect is driven by cultural or genetic drift. Sometimes, players using the gender-biased social learning strategy will have a string of bad luck. Potential learners will turn away, given the strategy's low average payoff. With enough bad luck, the trait can disappear from the population. The effect of drift depends on memory size because players with long memories entrench in their strategy. It's hard for new information to correct bad luck.

The magnitude of the drift effect is dependent on the population size. Smaller populations experience more drift and larger populations experience less. Figure three illustrates this relationship.

Both graphs represent populations with a memory of 10. The left side depicts a population with 1000 players. Drift is minimized. In large populations, strings of bad luck for some players tend to be balanced by strings of good luck for

[8]All simulation experiments reported in this paper use 1000 trials.

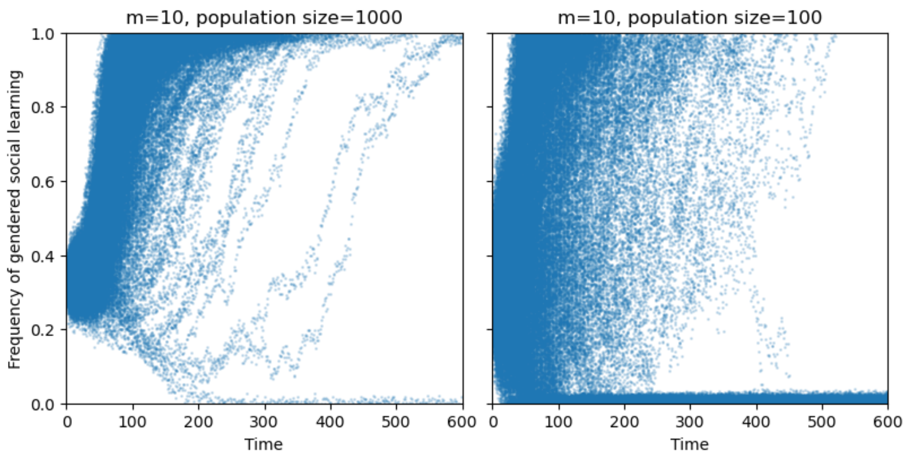

Figure 3: The effect of population size

other players. 3 trials failed to evolve gender-biased social learning in this large population. The right side depicts a population with 100 players. Drift is noticeably stronger and drove gender-biased social learning to extinction in 170 trials.

Drift is one source of variance in evolutionary models. Mutations are another. Mutations in the model might represent genetic mutation but they could just as easily represent cultural experimentation. Some people are mavericks, disregarding what is working well for others in favor of trying new things. Each round, players have a small probability of changing to a random learning strategy[9]. As figure four demonstrates, introducing mutations produces three effects - some of those effects are dependent on memory size.

First, mutations mitigate the effect of drift. The left column depicts trials with higher mutation rates than the right column. Notice that gender-biased social learning does not collapse in any trials in the left column. Drift causes collapse when bad luck steers players away from gender-biased social learning. Once eliminated from the population, no player will try it out. Mutations, by contrast, cause players to try out gender-biased social learning periodically, even when it's rare or extinct. Gender-biased learning gets a second chance to perform well. In the long run, given a non-zero mutation rate, the population will always discover the selective advantage of gender-biased social learning.

Second, mutations prevent uniform adoption of gender-biased social learning. In all four plots, there are substantial fluctuations in the frequency of gender-

[9]There could also be mutations at the level of behavioral strategy. This paper does not study models with behavioral mutations because they have basically no effect on gender-biased social learning. It is still selectively advantageous even when the behavioral environment is noisy.

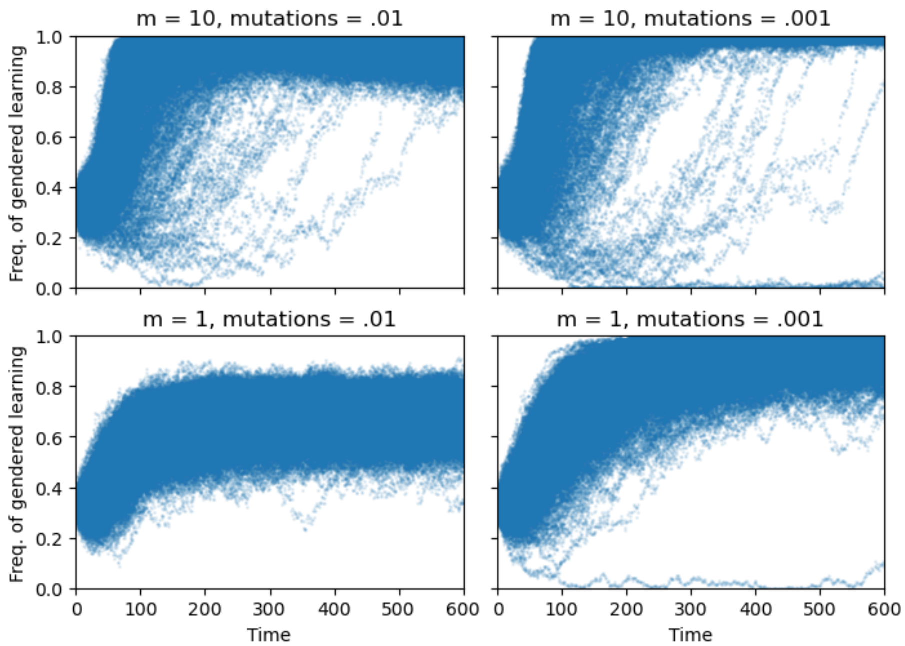

Figure 4: Mutation and memory interaction effects

biased social learning, even as the population approaches uniformity. When players switch from gender-biased social learning to generalized learning, they might still employ the right strategies to successfully coordinate in the division of labor. Other players may notice the success and follow suit with their learning strategy. In the long run, this shift will not be beneficial. Gender-biased learning ensures that one's strategies consistently adapt to the cultural conventions. But in the short run, experimentation is not penalized. The moral is that selection on learning strategies is fairly weak. Learning strategies are selected for only through their indirect effect on behavior. Players must take the correct actions to succeed. But how they decide which actions to take is a step removed from the practical stakes.

Third, the magnitude of mutation-driven fluctuations depends on the memory size and the mutation rate. Players with long memories will not easily be side-tracked. They know which learning strategy has the best long-run payoff. This is depicted in the top row of figure four. Populations with short memories, by contrast, experience substantial disruptions. When the mutation rate is high enough, the population may never achieve a uniform learning strategy (although selection still pulls the frequency of gender-biased social learning upward).

Does the disruptive effect of mutations prevent the formation of the gendered division of labor? In general, no. Even under conditions where the population fails to achieve uniform gender-biased social learning, the population still divides up tasks with a level of efficiency that approximates O'Connor's original results. Figure five depicts the average payoff in the population, a measure of how well players are dividing up labor. The plots use the same parameter settings as figure four.

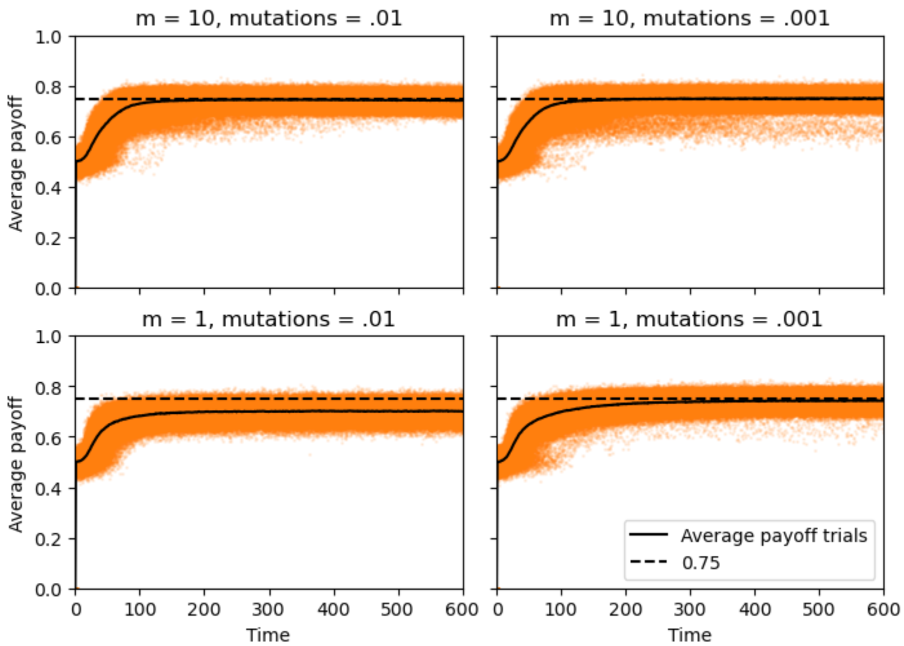

Figure 5: Mutation and memory effects on payoffs

Recall that populations in O'Connor's original model achieve an average payoff of 0.75, represented by the dashed line. In three of the four plots, the simulated average payoff nearly or exactly converges with the dashed line. This may be surprising, given that figure four depicts substantial deviation from uniform social learning. The bottom left plot shows this population achieves only a partial division of labor. The general conclusion is that the gendered division of labor can emerge even if uniform gender-biased social learning does not. Populations can tolerate regular, and sometimes substantial, experimentation with social learning strategies without destabilizing gendered conventions.

The underlying game is suspiciously egalitarian. It assumes that men and women benefit equally from the division of labor. It also assumes there is no conflict over who should perform a given activity. One can partially relax these assumptions and still achieve similar results.

Suppose that performing one side of the division of labor is more advantageous than performing the other. This assumption has some empirical and theoretical support. Some argue that male control over plow-based agriculture led to the historical development of patriarchy (Alesina, Giuliano, and Nunn 2013). If one group gains control over the plow, and subsequently the food supply, it provides substantial social power over the group that does not plow. In these circumstances, we should expect there to be some level of competition over how the division of labor forms.

O'Connor incorporates conflict into the payoff table by adding extra payoffs, e, to one of the activities. Suppose A represents childrearing and B represents plowing.

	A	B
A	(0, 0)	$(1, 1 + e)$
B	$(1 + e, 1)$	(0, 0)

Each player would prefer to plow most of all. But if you knew your partner would plow, it is in your best interest to settle for raising children. If no one tends to the children, disaster ensues. O'Connor analyzes this game and finds that we should still expect gendered social conventions to form[10]. Gender still facilitates coordination. Coordinating at all is still better than not coordinating, even if it results in a lower payoff for one group.

But one could ask a further question. Would gender-biased social learning arise, even when there is a conflict of interests over the equilibria? It is conceivable that the answer is no. If each group is vying for a separate outcome, then gender-biased social learning might be disadvantageous. The learning bias steers players toward adopting a conventional role and away from the powerful role. If men hold the most power in a society, it might be more advantageous to learn skills from men rather than from members of your own sex.

The model helps to clarify. Gender-biased social learning is still attractive but selection gets progressively weaker as the level of inequality gets stronger. The above line of reasoning has some truth to it. Competition dampens selection on social learning but does not eliminate it. Figure six depicts the frequency of gender-biased social learning for six different levels of e[11].

The black line represents the strength of selection. In all plots, the slope is positive, indicating that, given enough time and a small, non-zero mutation rate,

[10] That conclusion depends on the crucial assumption that there is no benefit from redundant plowing. If plowing was so rewarding that everyone should do it, then the gendered division of labor would not arise. This assumption only seems plausible if there is strong reason to think the activity is impossible in the absence of the division of labor. For example, if raising children and plowing are incompatible activities and both are necessary, then the conflict can arise.

[11] The memory size was set to 10 and a small mutation rate was introduced to prevent extinction due to drift.

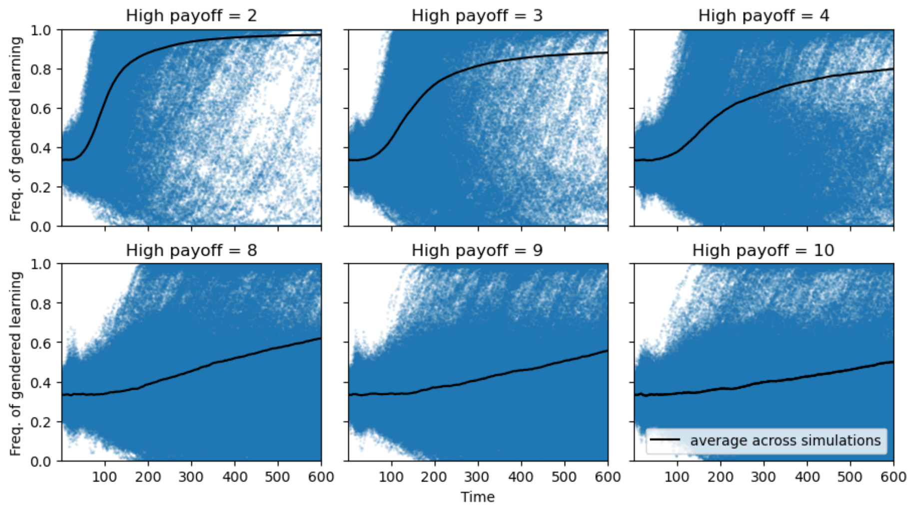

Figure 6: The effect of inequality

the population will eventually evolve gender-biased social learning. But selection may become extremely weak as the level of inequality in payoffs increases[12].

The explanation of this effect is fairly involved. There are two different stable states the population may settle into. In the first, there is no gendered division of labor. The population adopts some mixture of A and B actions that maximize expected payoffs. For example, if $e = 1$, then 66% of players will play B while 33% play A. The average payoff is 0.66. The A players coordinate most of the time but receive small payoffs. The B players coordinate less often but receive higher payoffs when they do. In the second stable state, there is a gendered division of labor. When players of the opposite sex play together, they always coordinate. This raises the average payoff of both groups. However, this increase in aggregate rewards is unequally distributed.

Moving from the first, low-payoff state to the second, high-payoff state requires high levels of gender-biased social learning. In its absence, each group will learn to mostly play B, the action that receives the higher payoff. Learning to coordinate through gender also requires one group to learn to settle for less, something evolutionary processes are not prone to do. Occasionally, due to drift or mutations, the level of gender-biased social learning will be high just as the population stumbles into a partial division of labor. This confluence of events can trigger a tipping point that drives the population from the first state to the second. The tipping point phenomenon is visible in the plots. Notice that there is an area of dense, dark blue at the top of each plot and in the middle. But between them, the plot is less dense. Each dense area describes the frequency

[12]In exploratory simulations, even when one activity is 25 times as good as the other, gender-biased social learning can still evolve.

of gender-biased social learning in a stable state. But when the tipping point triggers, the population will quickly move from one stable region to the other.

The lesson is that gender has a much easier time evolving if populations are trying to coordinate the division of equally rewarding activities. Inequitable gendered conventions can still evolve if coordinating unfairly is better than not coordinating at all. But the draw toward those conventions is substantially reduced as the level of inequality becomes more extreme.

The sensitivity analysis suggests a few general lessons. Gender-biased social learning will evolve in either large populations or the long run. Small levels of mutations combat the effect of drift but large levels can prevent the population from achieving uniformity in learning strategies. What level of mutations triggers which outcome depends on the memory size. Players with large memories are more at risk from drift than mutations. Even if the mutation rate is high relative to the memory size, the population can coordinate the division of labor with only moderate levels of gender-biased social learning. Inequality in payoffs has the most dramatic effect of all parameters. It changes which states are stable. The effect dampens, but does not eliminate, selection on gender-biased social learning.

We know neither the true parameter values of this model nor how to reliably estimate them. We should expect parameters to vary for different societies and different points in time. But this analysis suggests that the tendency toward gendered behaviors and social learning remains fairly general.

4. Implications

A recent body of work has employed cultural evolutionary models to understand the evolution of unfairness (O'Connor 2017; O'Connor and Bruner 2019, 2017; Bruner 2019; Henrich and Boyd 2008). Suppose that, instead of trying to coordinate, players are trying to bargain over a resource. Bargaining strategies take the form of asking for a certain proportion of the resource. Players might pursue a fair strategy, asking to divide the resource in half. But they could also pursue an aggressive bargaining strategy, asking for 60% of the resource, or an accommodating strategy, asking for 40%. If they can agree, everyone gets just what they asked for. If they cannot, both players get nothing. Evolving populations faced with this sort of problem will develop conventions for coordinating how much players should ask for. Either the convention is fair and both players ask for 50% or it is unfair and players adopt some mixture of 40% and 60% demands.

Bargaining problems have been explored extensively in the evolutionary game theory literature, with most analyses finding that the population generally develops fair bargaining conventions (Skyrms 1996, 2003; Alexander 2007). Those analyses assumed a homogeneous population; players did not have genders. The introduction of social categories changes the dynamics considerably. A convention can develop in which one group consistently makes aggressive demands on the other.

The literature has identified two kinds of mechanisms for producing inequality. One set aims to represent power differences. If one group can punish the other for failing to strike some kind of deal, the more powerful group will tend to be on the upside of an unfair bargaining convention. The less powerful group has more to lose from a failed bargain so will tend toward low-risk strategies. Similar results are found when one group is given a better baseline payoff or the ability to opt-out of bargaining for a small reward (O'Connor and Bruner 2017; O'Connor 2019).

The second set of mechanisms explores how differences in learning speed can influence outcomes. Suppose one group is much smaller than the other. For members of the small group, most of their interactions will be with people from the large group. As such, there will be pressure on them to quickly learn a strategy that plays well against the majority. The converse is true for the majority. They remain largely ignorant of how to interact with the minority. The majority will be walking around with a range of strategies against the minority, including plenty of aggressive strategies. Usually, aggressive strategies are risky but, given that the majority players do not have to use them often, they can afford to take the risk. In response to the high number of aggressive strategies, minority players tend to opt for the low-risk accommodating strategy (O'Connor 2017, 2019; O'Connor and Bruner 2019; Bruner 2019).

These models share the assumption that social learning is gender-biased[13]. Gender-biased social learning ensures that information flows in a segregated way. That is a necessary assumption for these models to produce inequality. Otherwise, neither group would develop a distinctive strategy. Whatever was most successful in one group would be adopted in the other.

The assumption of gender-biased social learning in bargaining models faces similar challenges to its role in division of labor models. As an explanation of the persistence of inequality in contemporary society, the assumption is sufficiently justified by appealing to the experimental evidence reviewed in section two. As an explanation of the origins of inequality, one needs to be careful.

The evolutionary explanation developed in this paper can support the bargaining models with two further assumptions. First, the kind of gender-biased social learning evolved to coordinate the division of labor must be fairly content-general. The bias cannot just steer how people learn about hunting and gathering. It must, at least, steer how people learn about bargaining and justice as well. Second, the gendered division of labor must evolve prior to the evolution of

[13]There are two important qualifications. First, many of these results hold when learning is individual, rather than social. If players use trial-and-error learning, the population can still produce inequitable conventions. Second, many of these models are interpreted to apply to racial and ethnic groups. The corresponding assumption is one of racial- or ethnic- biased social learning. There is no reason to think the explanation of gender-biased social learning developed here can automatically be extended to those learning bias.

gendered exploitation. Once evolved, this learning bias can shape the evolution of other social conventions.

This connection between the models may seem trivial. But it is not. Consider an alternative evolutionary justification. It is conceivable that bargaining problems could provide the necessary impetus for the evolution of gender-biased social learning. The learning bias could be selectively advantageous in helping people learn bargaining strategies appropriate for their social role. As exploitative bargaining conventions form, it is better to learn the conventions and which side one is on, rather than run afoul of them. Being exploited is bad. Being excluded from bargaining altogether is worse. One could incorporate the same menu of learning strategies into these models along with the `learn learning strategy` algorithm and let bargaining co-evolve with learning.

It turns out that the approach does not work. For all variants of the bargaining models, gender-biased social learning will not be selected for. The precise reasons vary between the bargaining models, but some high-level similarities hold. In order for men and women to adopt distinctive bargaining strategies, they need to already have the learning bias. Without it, a bargaining convention will form that is insensitive to gender. Under that convention, there is no selection for gender-biased learning because gender is unhelpful to strategic interactions. Without the learning bias, the mechanisms that previously induced regular inequality no longer work either. Equality becomes the most common outcome, as Skyrms and Alexander found in their early work. Gender-biased social learning must be fixed in advance by a prior evolutionary process. Successful co-evolutionary processes are not cheap - they require games with the just right structure.

This line of reasoning suggests a very general historical relationship between gender and gender inequality. We should expect a period of relative equality between genders prior to the formation of systematic inequality. Divisions of labor must develop and gender-biased social learning must become entrenched as preconditions for bargaining convention. Evidence to test this relationship may be found in the archaeological record but a review of that evidence is a task for future work.

Conclusion

Previous attempts to explain the cultural evolution of gender pointed to the empirical social learning literature. But when one looks at that literature, the finger points right back. Fortunately, not all circles are vicious, at least not when they are evolutionary ones. A co-evolutionary mechanism seems to work just fine under fairly general conditions. Exploring the co-evolutionary model provides useful resources for thinking about gender-biased learning assumptions deployed in other models. In particular, it constrains how we should think about the historical chronology of gender, the division of labor, and inequality.

These constraints provide empirically testable predictions which can verify if this modeling enterprise is on the right track.

References

Alesina, Alberto, Paola Giuliano, and Nathan Nunn. 2013. "On the Origins of of Gender Roles: Women and the Plough." *The Quarterly Journal of Economics* 128 (May): 469–530. https://doi.org/10.1093/qje/qjt005.Advance.

Alexander, Jason McKenzie. 2007. *The Structural Evolution of Morality.* Cambridge, UK: Cambridge University Press.

Axtell, Robert, Joshua M. Epstein, and H. Peyton Young. 2000. "The Emergence of Classes in a Multi-Agent Bargaining Model." Center on Social; Economic Dynamics.

Bandura, Albert. 1977. *Social Learning Theory.* Eaglewood Cliffs, NJ: Prentice Hall.

Bird, Rebecca Bliege, and Brian F. Codding. 2015. "The Sexual Division of Labor." *Emerging Trends in the Social and Behavioral Sciences*, 1–16. https://doi.org/10.1002/9781118900772.etrds0300.

Börgers, Tilman, and Rajiv Sarin. 1997. "Learning through reinforcement and replicator dynamics." *Journal of Economic Theory.* https://doi.org/10.1006/jeth.1997.2319.

Bruner, Justin P. 2019. "Minority (dis)advantage in population games." *Synthese* 196 (1): 413–27. https://doi.org/10.1007/s11229-017-1487-8.

Bussey, Kay, and Albert Bandura. 1984. "Influence of gender constancy and social power on sex-linked modeling." *Journal of Personality and Social Psychology* 47 (6): 1292–302. https://doi.org/10.1037/0022-3514.47.6.1292.

Currie, Adrian. 2016. *Rock, Bone and Ruin: An optimist's guide to the historical sciences.* Cambridge, MA: MIT Press.

Gurven, Michael, and Kim Hill. 2009. "Why do men hunt? A reevaluation of "Man the Hunter" and the sexual division of labor." *Current Anthropology* 50 (1): 51–74. https://doi.org/10.1086/595620.

Hawkes, Kristen. 1990. "Why Do Men Hunt? Benefits for Risky Choices." In *Risk and Uncertainty in Tribal and Peasant Economies*, edited by Elizabeth Cashdan. Boulder, CO: Westview Press.

Henrich, Joseph. 2016. *The Secret of Our Success: How Culture is Driving Human Evolution Domesticating Our Species and Making Us Smarter.* Princeton: Princeton University Press.

Henrich, Joseph, and Robert Boyd. 2008. "Division of labor, economic specialization, and the evolution of social stratification." *Current Anthropology* 49 (4): 715–24. https://doi.org/10.1086/587889.

Henrich, Joseph, and Richard McElreath. 2003. "The Evolution of Cultural Evolution." *Evolutionary Anthropology* 12 (3): 123–35. https://doi.org/10.1002/evan.10110.

Hoppitt, William, and Kevin N. Laland. 2013. *Social Learning: An Introduction to Mechanisms, Methods and Models.* Princeton, NJ: Princeton University Press.

Izquierdo, Luis R., Segismundo S. Izquierdo, and William H. Sandholm. n.d. *Agent-based Evolutionary Game Dynamics.* Pressbooks.

Kuhn, Steven L., and Mary C. Stiner. 2006. "What's a mother to do? The division of labor among Neandertals and modern humans in Eurasia." *Current Anthropology* 47 (6): 953–80. https://doi.org/10.1086/507197.

Losin, Elizabeth A.Reynolds, Macro Iacoboni, Alia Martin, and Mirella Dapretto. 2012. "Own-gender imitation activates the brain's reward circuitry." *Social Cognitive and Affective Neuroscience* 7 (7): 804–10. https://doi.org/10.1093/scan/nsr055.

Mcelreath, Richard, Adrian V Bell, Charles Efferson, Mark Lubell, Peter J Richerson, and Timothy Waring. 2008. "Beyond existence and aiming outside the laboratory : estimating frequency-dependent and pay-off-biased social learning strategies." *Philosophical Transactions of the Royal Society B: Biological Sciences* 363 (1509): 3515–28. https://doi.org/10.1098/rstb.2008.0131.

Mesoudi, Alex, Lei Chang, Sasha R. X. Dall, and Alex Thornton. 2016. "The Evolution of Individual and Cultural Variation in Social Learning." *Trends in Ecology and Evolution* 31 (3): 215–25. https://doi.org/10.1016/j.tree.2015.12.012.

Murdock, George P, and Caterina Provost. 1973. "Factors in the Division of Labor by Sex : A Cross-Cultural Analysis." *Ethnology* 12 (2): 203–25.

O'Connor, Cailin. 2017. "The cultural red king effect." *Journal of Mathematical Sociology* 41 (3): 155–71. https://doi.org/10.1080/0022250X.2017.1335723.

———. 2019. *The Origins of Unfairness: Social Categories and Cultural Evolution.* Oxford: Oxford University Press.

———. 2020. *Games in the Philosophy of Biology.* Cambridge, UK: Cambridge University Press. https://doi.org/10.1017/9781108616737.

O'Connor, Cailin, and Justin Bruner. 2017. "Power, Bargaining, and Collaboration." In *Scientific Collaboration and Collective Knowledge: New Essays.* October 2021. Oxford, UK: Oxford University Press. https://doi.org/10.1093/oso/9780190680534.001.0001.

———. 2019. "Dynamics and Diversity in Epistemic Communities." *Erkenntnis* 84 (1): 101–19. https://doi.org/10.1007/s10670-017-9950-y.

Perry, David G., and Kay Bussey. 1979. "The social learning theory of sex differences: Imitation is alive and well." *Journal of Personality and Social Psychology* 37 (10): 1699–1712. https://doi.org/10.1037/0022-3514.37.10.1699.

Sankaran, Kirun. 2020. "What's new in the new ideology critique?" *Philosophical Studies* 177 (5): 1441–62. https://doi.org/10.1007/s11098-019-01261-9.

Shutts, Kristin, Mahzarin R. Banaji, and Elizabeth S. Spelke. 2010. "Social categories guide young children's preferences for novel objects." *Developmental Science* 13 (4): 599–610. https://doi.org/10.1111/j.1467-7687.2009.00913.x.

Skyrms, Brian. 1996. *Evolution of the Social Contract*. Cambridge, UK: Cambridge University Press.

———. 2003. *The Stag Hunt and the Evolution of Social Structure*. Cambridge University Press. https://doi.org/10.1017/CBO9781139165228.

Smaldino, Paul E. 2020. "How to translate a verbal theory into a formal model." *Social Psychology* 51 (4): 207–18. https://doi.org/10.1027/1864-9335/a000425.

Wilensky, Uri, and William Rand. 2015. *An Introduction to Agent-Based Modeling: Modeling Natural, Social, and Engineered Complex Systems with Netlogo*. Cambridge, MA: MIT Press.

Wood, Lara A, Rachel L Kendal, and Emma G Flynn. 2013. "Whom do children copy ? Model-based biases in social learning." *Developmental Review* 33 (4): 341–56. https://doi.org/10.1016/j.dr.2013.08.002.