Ownership and trade from evolutionary games

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Abstract

This article describes how ownership status serves as a natural asymmetrizing criterion enabling resolution of property conflicts. Two new evolutionary game models are presented where ownership and trade emerge from anarchy as evolutionary stable strategies.

1. Introduction

In the last three decades, behavioral ecology has made strides in understanding the origin and utility of behavioral traits in animal societies (Maynard Smith, 1988; Wilson, 1975). Much of this success has come within the analytic framework of evolutionary game theory. Evolutionary games, which mimic the dynamics of Darwinian natural selection, differ fundamentally from classical games (Maynard Smith, 1988). While the latter focus on strategic interactions between rationally calculating agents, evolutionary games model repeated interactions between adaptive but otherwise non-thinking agents.

As one tends to believe humans think, it is not surprising that classical game theory has established a dominant position in law and economics (Baird, Gertner, & Picker, 1994) while evolutionary game theory has attracted much less attention.[1] A notable exception to this trend is Hirshleifer, who pointed out parallels between evolved animal behaviors (and their game theory models) and economically efficient human practices (Hirshleifer,

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[1] This is not to suggest the absence of a strong evolutionary tradition in law. Scholars who have written about the evolution of law include: Boyd and Richerson (1985), Cooter and Kornhauser (1980), Elliott (1985), Ellickson (1991), Epstein (1979), Hirshleifer (1982), Huang and Wu (1994), Johnston (1996), Priest (1977), Paul (1977), and Yee (1998).

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1977, 1980, 1982). Hirshleifer proposed three metallic norms in particular: the “Golden Rule of communal sharing,” the “Silver Rule of private rights,” and the “Iron Rule of dominance.” Each, he asserted, has evolved because they have sufficient socioeconomic advantages.

This article develops an evolutionary game model of property ownership and trade. To start, it extends and interprets a well-known evolutionary model of animal territoriality as a model of human property ownership. That one could do this is perhaps not surprising. The more surprising result is that trade—the bilateral transfer of property for renumeration—then emerges as a strategy which is evolutionarily preferred over permanent ownership without trade. In other words, traders are evolutionarily superior to owners who do not trade. The identification that trade is an evolutionary stable strategy in evolutionary game theory is the main contribution of this article.

The swallowtail butterfly, *Papilio zelicaon*, provides a provacative example of what may underlie animal territorial behavior[2] (Maynard Smith, 1988, p. 214). Because the swallowtail lives in low density populations, one might expect matchmaking—the finding of a sexual partner—to be a problem. This problem is solved in swallowtail society by “hilltopping.” Males establish territories at or near the tops of hills and wait for virgin females, who instinctively seek out hilltops to mate. Since there are typically more males than hilltops, most males are relegated to disadvantageous positions lower down the slopes, where they attempt to waylay females on their way uphill. Although the lower altitude males sometimes succeed, hilltop males mate most. Curiously, despite their enviable estates, hilltoppers are seldom challenged by intruders. On occasion when an intruder does confront a hilltopper, the visitor tends to retreat after a brief, mild contest.

How is hilltop occupancy negotiated? In experiments, Larry Gilbert[3] tested two alternative explanations: (A) potential intruders are intimidated from invading because hilltoppers are physically strongest, and because this fact is perceived by the intruders; or (B) swallowtails defer to prior possessors, that is, whoever first stakes out a hilltop is granted a socially-established privilege to keep it (not unlike in the Anglo-American doctrine of adverse possession).

In a series of experiments with pairs of randomly selected male butterflies, Gilbert ruled out A, and found support for the prior possessor theory, B, as follows. He convinced each butterfly of a pair that it was the sole occupier of the same hilltop by letting it be the hilltopper on alternate days. On its days off, Gilbert kept the sidelined butterfly unaware of its counterpart’s existence by confining it in dark room. After a couple of weeks, each male clearly acted as the hilltop’s rightful proprietor, chasing away all comers, who invariably retreated without much protest. When Gilbert finally released both males to the same hilltop on the same day, an abnormally prolonged contest between the two “proprietors” ensued, lasting many minutes and causing serious injury to each contestant. As a result, Gilbert concluded that deference to prior hilltop possessors is an instinctive trait of swallowtails.

[2] Other species, such as the hamadryas baboon, have been documented to exhibit similar behavior.

[3] Because a caterpillar virus wiped out his butterfly population before Gilbert completed his studies, Gilbert’s original study, the one described in Maynard Smith (1988), was never published (L.E. Gilbert, private communication to Yee). In any case, R. Lederhouse describes similar observations of a closely related butterfly species (see Scriber, Tsubaki, & Lederhouse, 1995).

Maynard Smith (1982) and others hypothesized that such instincts evolved by natural selection of the fittest and constructed evolutionary game theories modeling the evolutionary processes. In these models, deference to possession—a dispute resolution strategy based on pre-existing status—is evolutionarily preferred over an always-fight strategy, which costs too much, and a never-fight strategy, which yields too little.

Ownership conventions in human societies range from the simplest unspoken norms, such as not cutting ahead of somebody else in a grocery store queue to much more involved rights bundles expressed in the Common Law. A broad range of viewpoints (Rose, 1985), ranging from Locke's labor-mixing theory of property[4] to law and economics[5] may be called upon to justify them. Legal property rights can be enforced by various combinations of liability and injunctive remedies (e.g. Calabresi & Melamed, 1972).

Whatever the justifications, most ownership rights bundles consist of two primitive strands: (a) possession, the right to occupy or possess what one owns, and (b) trade, the right to buy and sell ownership. By constructing evolutionary game theory models, I will illustrate how evolutionary forces can serve to establish these two strands as stable strategies. The trade model shows that those who trade are evolutionarily preferred over possessors who do not. What is new here is that *evolutionary forces are enough by themselves to establish possession and, given possession, the practice of trade*.

Section 2 reviews Maynard Smith's (1982) construction of evolutionary stable strategy (ESS) and argues that ESSes have interpretation as social norms. Sections 3 and 4 present two models corresponding, respectively, to the two strands of ownership. In Section 3 model, possession is an ESS; in Section 4, possession with the right to trade is an ESS.

2. Evolutionary stable strategies

Social benefits come only at a price: for every benefit accrued, there must be set of behavioral constraints or obligations to be fulfilled. Social norms—prevalent responses to recurring social situations—are the reciprocal constraints enabling the social benefits.

Evolutionary game theory provides a quantitative dynamical theory of how such social constraints on behavior can emerge from anarchy.[6] The basic ingredients of evolutionary game models for our purposes are:

- a self-contained community of disputants interacting in repeated, random pairwise encounters;

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[4] In a nutshell, Locke's view is that one owns one's body and, by extension, the fruits of his body's labor. Hence, first useful possession establishes a property right (Epstein, 1979).

[5] The normative law and economics view may be summarized as follows. Property rights may be thought of as a bundle of strands of primitive rights. Particular strands—tailored to the situation—are granted to encourage social welfare optimizing use and investment. A benefit–cost balance determines whether a particular strand should be granted enforcement. Costs include enforecement costs (Posner, 1992).

[6] Axelrod (1986) argues that social norms cannot survive unless there is a secondary norm enforcing the first norm. This implies the need for a tertiary norm to enforce the secondary norm, and so forth ad infinitem. (See also, Lomborg, 1996; Martinez Coll & Hirshleifer, 1991.) In contrast, the elegance of evolutionary stable strategies (as exemplified by the models herein) is that, within the context of the game, they do not require such an infinite hierarchy of supporting norms.

- who, at each encounter, select from a predetermined[7] menu of strategies, say, $\{\alpha, \beta, \gamma, \ldots\}$ which may be either pure or mixed;
- if player #1 chooses strategy α and #2 chooses β, the payoff to player #1 is denoted $w_{\alpha\beta}$, which is determined entirely by α and β;
- a round consists of many random encounters for each player. After each round, the community undergoes "natural selection," in which strategies replicate in proportion to how far above average their scores in the just-completed round were; those with below average scores die off in proportion to how far below average they were.

Consequently, an adaptive population evolves according to a set of coupled first-order differential equations—one corresponding to each strategy—in the same spirit as the Malthusian predator–prey relations. Solving the equations yields a phase diagram in strategy space, which typically has several fixed points (Friedman, 1991). Some of these fixed points are attractive: populations always evolve into them so that they are evolutionarily stable against subversive mutations. Each attractive fixed point in a phase diagram represents an "evolutionary stable strategy (ESS)."

In other words, an ESS is a possible mode of behavior that might lock-in. Thus, an ESS can be interpreted as a social norm.

For purposes of this article, it will be sufficient to state a criteria defining ESS(es) given the game's defining payoff matrix.[8] To this end, for a given game strategy α_* is an ESS if, starting from a status quo where α_* is the norm, it is not possible for insurgents to achieve higher payoffs with a renegade strategy, say, γ. Algebraically, this means α_* is an ESS if *either*

$$w_{\alpha_*\alpha_*} > w_{\gamma\alpha_*}, \quad \forall\gamma \tag{1}$$

or

$$w_{\alpha_*\alpha_*} = w_{\gamma\alpha_*} \quad \text{and} \quad w_{\alpha_*\gamma} > w_{\gamma\gamma}, \quad \forall\gamma. \tag{2}$$

Condition (2) is sufficient to establish an ESS because, even if $w_{\gamma\alpha_*} = w_{\alpha_*\alpha_*}$, invaders behaving according to γ cannot successfully gain a foothold if they perform so poorly against each other that they prevent themselves from becoming a sizable fraction of the population. Note that whether a strategy is an ESS or not depends on the strategy space, the set of competing strategies. What is an ESS in one strategy space may cease to be an ESS if the strategy space is expanded to include other strategies. Also, games can (and usually do) have more than one ESS.

Of direct relevance to us is the Hawk–Dove game (Maynard Smith & Price, 1973), whose payoffs are depicted in Fig. 1. In this game, two equally matched parties vie for the same asset, worth $\$V$ to each. (Imagine two randomly paired strangers fighting over a parking space at a crowded shopping mall.) Suppose only two strategies, Hawk (H) and Dove (D), are available. Hawks always fight and, since both parties are equal, in a fight each Hawk

[7] In more ambitious formulations, the strategy space is permitted to evolve via mutations in analogy to genes in biology.

[8] From Maynard Smith (1982). Other authors (e.g. Zeeman, 1981) have pointed out that these criteria expressed in terms of payoff matrix elements do not always recover all the aforementioned attractive fixed points. For our models, the technical distinction is immaterial.

		#2	
		H	D
#1	H	$\left(\frac{V}{2} - h, \frac{V}{2} - h\right)$	$\left(V, 0\right)$
	D	$\left(0, V\right)$	$\left(\frac{V}{2}, \frac{V}{2}\right)$

Fig. 1. Payoffs to disputants (#1, #2) in the two-player "Hawk–Dove" game. Each disputant values the asset at $\$V$. Fighting has expected harm $\$h$ to each Hawk, and yields a (1/2) chance of winning $\$V$. If both are Doves ($D$), they have a (1/2) chance of getting the asset without fighting. If one is a Hawk while the other is a Dove, the Dove retreats leaving the prize for the Hawk.

has only a one-half chance of winning the asset. Fighting has an expected total cost to each participant of $\$h$. In addition to the expected injury, h contains all other costs including the expected energy expenditure and any risk-bearing costs. Doves retreat when confronted by a Hawk. If two Doves meet, a random one of the two Doves retreats and leaves the other to the spoils.

In neoclassical game theory (e.g. Baird, Gertner, & Picker, 1994), $(1/2)V > h$ corresponds to the Prisoner's Dilemma while $(1/2)V < h$ corresponds to the Chicken game. In the Prisoner's Dilemma, H is called "defection" and defection is the unique Nash equilibrium strategy for both players. In the Chicken game, the unique Nash equilibrium is for one player to be the Chicken (D) and the other to be the Hawk (H).

When $(1/2)V > h$ (the Prisoner's Dilemma case), H is an ESS and D is *not* by virtue of Criterion (1). In other words, aggressiveness is evolutionarily preferred when the rewards outweigh the costs of fighting. Note that this does *not* mean H optimizes social welfare. In fact, an all-Dove population maximizes social welfare.

When the possibility of serious injury is sufficiently large, $(1/2)V < h$ (the Chicken game case). In this case, neither pure strategies H or D are ESSes. It turns out that the only ESS (within the H–D strategy subspace) is a mixed strategy $\alpha_* = PH + (1 - P)D$, where $P \equiv (1/2)V/h$. This mixed strategy can be achieved in two ways. Either the population is homogeneous and at an encounter each individual exercises H with probability P, or the population is comprised of fraction P Hawks and $(1 - P)$ Doves. In either case, the more potential costs exceed potential gains the less evolutionarily attractive hawkishness is.

The material in this section was established by Maynard Smith (1982) and others. While the Hawk–Dove game has provided insights into animal behavior, it is too simple to allow for more sophisticated human strategies. Humans act like neither Hawks, Doves, nor mixtures thereof. Rather, we have more sophisticated options. The next section turns to one of them.

3. Possession as an ESS

"Finder's keepers" and "first come, first serve" are not only basic thumb rules in playground citizenship, they are powerful norms that have been recognized by the courts and applied widely in such varied settings as adverse possession, abandoned property, fisheries,

		#2 H	#2 D	#2 P
#1	H	$\left(\frac{V}{2}-h, \frac{V}{2}-h\right)$	$(V, 0)$	$\left(\left(\frac{V}{2}+h\right)f + \frac{V}{2}-h, \left(\frac{V}{2}-h\right)f\right)$
	D	$(0, V)$	$\left(\frac{V}{2}, \frac{V}{2}\right)$	$\left(\frac{V}{2}f, \frac{V}{2}(1+f)\right)$
	P	$\left(\left(\frac{V}{2}-h\right)f, \left(\frac{V}{2}+h\right)f + \frac{V}{2}-h\right)$	$\left(\frac{V}{2}(1+f), \frac{V}{2}f\right)$	(fV, fV)

Fig. 2. Payoffs to disputants (#1, #2) in the "Hawk–Dove–Possessor" game. If Possessor P owns a piece of land, it will fight for it as a Hawk; if P's opponent is the owner, P defers to him and acts as a Dove. f is the fraction of time on average a disputant expects to be in the role of owner.

wildlife, seabed minerals, groundwater rights, intellectual property, debt collection, oil and gas, pollution permits, the radio frequency spectrum, satellite orbits, and ownership of wartime spoils.

To model this norm as an ESS, introduce the "Possessor (P)" strategy:

$$P \equiv \begin{cases} H, & \text{if current owner}, \\ D, & \text{if current intruder}. \end{cases}$$

The Possessor strategy models the practice of "possession." Unlike Hawks and Doves, Possessors observe convention based on their status; their behavior depends on whether they are the owner or intruder.

Fig. 2 depicts the Hawk–Dove–Possessor game payoffs. If $f = (1/2)$, the Hawk–Dove–Possessor game reduces to the Hawk–Dove–Bourgeois game (Hirshleifer, 1982; Maynard Smith, 1988, pp. 22–23). What distinguishes the Hawk–Dove–Possessor game from the Bourgeois game is the parameter f. f is the expected fraction of confrontations in which a disputant anticipates she will be in the role of owner. We will show that P is the unique ESS for *all* f in the interval (0, 1). This implies that the Possessorship strategy is robust to the wealth (or dearth) of ownership opportunities available—all one requires is a non-zero chance ($f \neq 0$) to be an owner.

The payoffs of the Hawk–Dove–Possessor game are motivated as follows. First, the parameter f has the following interpretation. Imagine a neighborhood in which everyone possesses a separate (but otherwise identical) plot of land. At the same time, everyone is wandering the neighborhood interested in obtaining possession of additional plots. Suppose that each agent wanders randomly throughout the neighborhood so that, in the repeated disputes which arise, each disputant is in the role of owner fraction f the time and intruder the other $1 - f$. For instance, if there were N disputants each owning one plot of land, in a round-robin tournament every disputant would intrude $N - 1$ times and be reciprocally intruded upon $N - 1$ times. In this case, $f = (1/2)$ because every disputant is an owner half the time and an intruder the other half.

Also of interest is when land is scarce and not everyone can own a plot. Then the probability f of being an owner in a random encounter is no longer (1/2), but will be some positive number less than that. To obtain an expression for f, let n denote the number of available plots, and N the total number of disputants. Assume $N \geq n$ and that N is very large. Assume everyone has an equal chance to be an owner and nobody owns more than one plot of land at any time. Then the chance to be an owner is $g = (n/N)$. The total number of encounters a plot-owner endures in a round-robin tournament where every disputant (owners and non-owners alike) attempts to intrude once on every alien plot is $(N-1)+(n-1)$ because the owner defends his land once against the other $N-1$ disputants and intrudes once on the other $n-1$ plot owners. Hence, ignoring the higher order effect of what happens when property transfers resulting from encounters lead to a disputant temporarily owning more than a single plot of land, the fraction of encounters where *an owner* plays the role of owner is

$$\frac{N-1}{(N-1)+(n-1)}.$$

The overall fraction f of time a random disputant plays the role of owner in an encounter is

$$\begin{aligned} f &= (\text{chance to be an owner}) \times (\text{fraction of encounters in owner's role if owner}) \\ &= g \times \left(\frac{N-1}{(N-1)+(n-1)}\right) = g \times \left(\frac{1-(1/N)}{1+(n/N)-(2/N)}\right). \end{aligned}$$

In the limit where the number N of disputants is large and the ratio $g = n/N$ is finite (n may or may not be large depending on the value of g, but n is strictly less than N),

$$\lim_{\substack{N \mapsto \infty \\ g=n/N}} f \sim \frac{g}{1+g}.$$

In this limit, $0 \leq f \leq (1/2)$ because $0 < g < 1$. In particular, $f = 0$ when the chance of land ownership is zero ($g = 0$). When land is scarce ($n \ll N$), the chance of land ownership is small ($g \ll 1$) and so is $f \sim g$. On the other hand, when the chance of land ownership is almost certain[9] ($g \mapsto 1$), then $f = (1/2)$.

In the Hawk–Dove–Possessor game, at each encounter a disputant can either behave like a Hawk, a Dove, or a Possessor. Fig. 2 depicts the payoffs of the Hawk–Dove–Possessor game. In deriving Fig. 2, payoffs have been averaged over many encounters. Since disputants are owners f of the time, and intruders $1-f$ of the time, the payoff to disputant #1 is the weighted average of two conditional payoffs:

$$w = f w\|_{\text{owner}} + (1-f) w\|_{\text{intruder}}.$$

For example,

$$w_{\text{PH}} = f(\tfrac{1}{2}V - h) + (1-f) \times 0 = (\tfrac{1}{2}V - h) f,$$

[9] When land is plentiful relative to the number of disputants ($n \gg N$), the chance g for a disputant to be an owner is given by a complex combinatoric function if disputants are allowed to own more than one plot of land; the expression $g = n/N$ is valid only when ownership is capped at one plot per person.

$$w_{HP} = fV + (1-f)(\tfrac{1}{2}V - h) = \tfrac{1}{2}V - h + (\tfrac{1}{2}V + h)f,$$

and

$$w_{PP} = fV + (1-f) \times 0 = fV.$$

When $(1/2)V < h$ (the Chicken game case), P is the only ESS of the Hawk–Dove–Possessor game. (The reader is invited to confirm this using Conditions (1) and (2).) In fact, one can go further and prove there is no mixed ESS so that P is the unique ESS if the strategy space is H–D–P. As this is true for *any* value of $f \in (0, 1)$, it takes only a *tiny* (any non-zero) chance f of ownership to establish P as an ESS. The fact that P is not an ESS exactly at $f = 0$ is moot because $f = 0$ means there is no property to be owned ($n = 0$).

In defining the Hawk–Dove–Possessor payoff matrix, I assumed that owners and intruders value the disputed plots equally, that it costs owners and intruders the same to engage, and that owners and intruders each have equal chances of winning a fight. In real life, due to informational advantages of being an owner, owners probably value and can defend their properties more and better than intruders. So it is likely that Possessorship is even more preferred than in this stylized model. What the Hawk–Dove–Possessor model shows is that *Possessorship is evolutionarily stable despite ignoring all the likely advantages an owner has over an alien intruder*.

While P is an ESS for the Chicken game, it does not resolve the Prisoner's Dilemma. When $(1/2)V > h$ (the Prisoner's Dilemma case), H remains the only pure strategy ESS. When the expected gain from fighting exceeds expected losses, aggressiveness is evolutionarily preferred over dovishness and Possessorship.

Possessor is an ESS for the Chicken game because it provides a predictable and costless mechanism for resolving disputes. As in the game, possession in the real world serves to establish an asymmetric dispute resolution mechanism in an otherwise symmetric situation. This role is consistent with the prolific public notice requirements usually associated with possession, including title registration requirements and the adverse possession doctrine, under which owners can be divested of property for failing to protest against dispossession in a timely manner.

The utilitarian value of possession was recognized early on in the Common Law. In *Pierson v. Post*[10] a famous wild-fox case from the nineteenth century, a hunter, Post, had a fox in his gunsight but before he could fire an interloper killed the fox and ran off with the prize. The indignant Post sued the interloper on the theory that his pursuit of the fox established his right to have it. The court disagreed. It held that possession requires a clear act putting the world on notice that the "pursuer has an unequivocal intention of appropriating the animal to his individual use." (Id. at 178). Gaining property rights over a wild animal requires either establishing physical control over it or mortally wounding it.

3.1. Why not Anti-Possessor?

I asserted at the beginning of Section 3 that the virtue of Possessorship is dispute resolution via an objective symmetry-breaking criterion. Yet, Possessorship is not the only

[10] *Pierson v. Post*. 3 Cai. R. 175 (N.Y. Sup. Ct. 1805).

symmetry-breaking mechanism one can imagine. In particular, consider its mirror image, the "Anti-Possessor (AP) strategy":

$$\mathrm{AP} \equiv \begin{cases} D, & \text{if current owner}, \\ H, & \text{if current intruder}. \end{cases}$$

One might reasonably guess that Anti-Possessorship would serve just as well as Possessorship as a symmetry-breaking device. AP indeed *is* an ESS in a game consisting of Hawks, Doves, and Anti-Possessors.

In animal societies, AP is rare, but not totally unheard of. The social spider *Oecibus civitas* lives together in groups, but each constructs its individual web. If a spider is driven from its web, it may dart into the web of a neighbor. If the neighbor is in residence, it does not expel the intruder, but instead darts out into somebody else's web. As a result, dislocating a single spider may trigger a chain reaction—a game of musical webs (Maynard Smith, 1982, p. 96).

It is apparent why P is more common than AP in both nature and culture. AP is disfavored due to nomadicy costs. In an AP culture, citizens are forced to alternate as owners and intruders in an unending tag-team match. Due to relocation costs, AP is not as viable as P.

4. Trade as an ESS

While possession retention is the first strand of property rights, the trading is the second strand. Trade is efficient because if an intruder values a property at $\$V$ while the current owner values it at $\$v < \$V$, then both benefit if the owner sells it to the intruder for $\$x$ where

$$v < x < V.$$

Beyond restricting x to the interval (v, V), the model here does not have anything to say about whether the transaction price $\$x$ is paid in money or another asset of value $\$x$. The model also does not specify how the value of x is determined—whether by case-by-case negotiation or by an exogenously given recipe. In this section, I will simply show that trading is an ESS for *any* $x \in (v, V)$. The point is that trade is evolutionarily preferred over stoic possessorship (P).

Suppose in every encounter, the two disputants do not value the disputed property equally because, for example, they always have slightly different reasons for wanting the property. Let $\$V$ and $\$v$, with $v < V$, denote the two mismatched valuations. Define a "Trader (T)" as a Possessor who is willing to sell or buy for $\$x$ when dealing with a fellow Trader. In particular, when both owner and intruder of a particular encounter are Traders, and the intruder values the property more (e.g. at $\$V$) than the owner, he will want to purchase the property from the owner for $\$x$, where $v < x < V$. Symbiotically, a Trader–owner who values the property less (e.g. at $\$v$) than a Trader–intruder will readily agree to sell the property to the latter for $\$x$. In other words,

$$T \equiv \begin{cases} P, & \text{if counterpart is not } T, \\ \begin{cases} \text{sell for } x, & \text{if } v\text{-valuing owner}, \\ \text{buy for } x, & \text{if } V\text{-intruder}, \\ P, & \text{otherwise}. \end{cases} & \text{if counterpart is } T, \end{cases}$$

#2

#1	H	D	P	T
H	(w_{HH}, w_{HH})	(w_{HD}, w_{DH})	(w_{HP}, w_{PH})	(w_{HT}, w_{TH})
D	(w_{DH}, w_{HD})	(w_{DD}, w_{DD})	(w_{DP}, w_{PD})	(w_{DT}, w_{TD})
P	(w_{PH}, w_{HP})	(w_{PD}, w_{DP})	(w_{PP}, w_{PP})	(w_{PT}, w_{TP})
T	(w_{TH}, w_{HT})	(w_{TD}, w_{DT})	(w_{TP}, w_{PT})	(w_{TT}, w_{TT})

$w_{\alpha\beta} \equiv$

	H	D	P	T
H	$\frac{V+v}{4} - h$	$\frac{V+v}{2}$	$\frac{V+v}{4}(1+f) - h(1-f)$	$\frac{V+v}{4}(1+f) - h(1-f)$
D	0	$\frac{V+v}{4}$	$\frac{V+v}{4} f$	$\frac{V+v}{4} f$
P	$\frac{V+v}{4} f - hf$	$\frac{V+v}{4}(1+f)$	$\frac{V+v}{2} f$	$\frac{V+v}{2} f$
T	$\frac{V+v}{4} f - hf$	$\frac{V+v}{4}(1+f)$	$\frac{V+v}{2} f$	$\frac{V}{2} - (\frac{1}{2} - f)x$

Fig. 3. The top table depicts the payoffs to disputants (#1, #2) in the Hawk–Dove–Possessor–Trader game. The lower table lists the payoff values $w_{\alpha\beta}$ for $i, j \in \{H, D, P, T\}$. A disputant is an owner fraction f of the time and an intruder $1 - f$ of the time. One party values the disputed property at $\$V$ and the other at $\$v < \$V$. Half the time, the V-valuer is the owner, half the time the intruder. If both owner and intruder are Traders (T) and the intruder values the property more, he purchases from the owner for $\$x$ where $v < x < V$.

Fig. 3 depicts the payoffs of the Hawk–Dove–Possessor–Trader game ("Trader game" for short). In deriving the payoff matrix, I have assumed that disputants are owners fraction f of the time, and intruders $1 - f$ of the time. Additionally, each encounter is between a disputant valuing the property at $\$V$ and one valuing it at $\$v$. Thus, the payoff to disputant

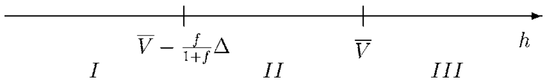

Fig. 4. $\bar{V} \equiv V + v/4$ is average value each party would walk away with if they equally shared the asset. $\Delta \equiv (V - v/2) > 0$ is the *incremental* expected gain of trading. h is the cost of fighting. In Region I (where $h < \bar{V} - f/(1+f)\Delta$), H is the unique pure strategy ESS. In Region II (where $\bar{V} - f/(1+f)\Delta < h < \bar{V}$), both T and H are possible ESSes. In Region III (where $h > \bar{V}$), T is the unique pure strategy ESS.

#1 is the weighted average of four conditional payoffs:

$$w = \frac{f}{2}(w_{|V\text{-valuing owner}} + w_{|v\text{-valuing owner}}) + \frac{1-f}{2}(w_{|V\text{-valuing intruder}} + w_{|v\text{-valuing intruder}}).$$

For instance,

$$w_{\text{TT}} = \frac{f}{2}(V + x) + \frac{1-f}{2}(V - x + 0) = \frac{1}{2}V - \left(\frac{1}{2} - f\right)x.$$

The ESSes of the Trader game depends the relative values of the cost of fighting h, the average spoils of sharing without fighting $\bar{V} \equiv (V + v/4)$, and the *incremental* expected per party gain from trading $(V - v/2)$. As depicted in Fig. 4, when the cost of fighting is small (Region I), H is an ESS and T is not. On the other hand, when the cost of fighting is comparably large (Region III), T is an ESS and H is not.

When fighting cost is intermediate (Region II), both H and T are ESSes. If $V = v$, then $\Delta = 0$ and Region II is subsumed by Region I. Hence, Region II owes its existence to a valuation discrepancy between owner and intruder. In Region II, hawkishness is viable because the cost of fighting is less than the expected spoils $\bar{V}$. At the same time, the cost of fighting exceeds the expected harm from not Trading, so Trading is also viable. As it is, if everyone is trading in Region II, a disputant is better off to trade. On the other hand, if everyone is a Hawk in Region II, a disputant is advised to also be a Hawk.

These results follow from verifying the necessary and sufficient ESS Criteria (1) and (2). The intuition for why Region III ($h > \bar{V}$) is a *trade-only* region is as follows. In this case, within the H–D–P strategy subspace P is the ESS (for the same reasons why P is the ESS in the Hawk–Dove–Possessor game). T fares no worst than P against Hawks and Doves since Traders and Possessors act the same way against Hawks and Doves. The remaining issue is why T fares better than P within the $P - T$ subspace. The reason is because, in trades the seller–owner always nets a surplus of \$$(x - v)$ while the buyer–intruder nets a surplus of \$$(V - x)$. Because both parties gain and nobody loses in a trade, Traders fare better than Possessors and T is the only pure strategy ESS.

Clearly, Region III corresponds to bartering in ancient societies and commerce in modern ones. When the cost of fighting is high, trade evolves.

Likewise, Region I is reminiscent of nations fighting over land, oil fields, and governance structures. When the expected value of the asset far exceeds the cost of war, hawkishness emerges.

Region II, when fighting cost is intermediate, is the most interesting. In this case, *either* H or T can emerge and, once one of them does, it locks in as the ESS. However, either H or T has an equal ex ante chance of emerging. For instance, Region II may help explain some litigation practices in the United States, but whether it does or not is difficult to assess because determining the parties' costs and benefits in these situations is difficult. Suppose costs are such that Region II applies in some legal disputes, such as bankruptcy or tort cases. Then bankruptcy cases may be more likely settled out of court (a T strategy) while tort litigation may go to trial more frequently (an H strategy) simply because historically a T strategy has emerged as normal practice in bankruptcy while an H strategy is the norm in tort litigation. Once an ESS is established, the strategy (T or H) becomes the modus operandi when that kind of dispute arises even though the other strategy could fare equally well if everyone were to adopt it instead.

Finally, Fig. 4 highlights the cost h, which is exogenously given, as the critical determinant of whether T or H or both are evolutionarily favored. As law has the power to change h by exacting extra penalties and fees on disputants, an implication of the Trading game is that law can inspire or hinder the evolution of trade by its assessment of penalties on hawkishness or trading.

5. Concluding remarks

The Hawk–Dove–Possessor game and the Hawk–Dove–Possessor–Trade game provide two messages. The first message is that deference by intruders to owners is evolutionarily preferred over non-status-based behavior. This is because prior possession provides a ready asymmetrizing criterion enabling resolution of possession conflicts. Individuals who avoid transactions costs by resolving conflicts based on a cultural asymmetrizing criterion are better off than those who do not.

Can one do better than mere possession? The second message answers this question affirmatively. A Trade strategy trumps Possessorship with no trade. Trade is the ability to buy and sell according to what optimizes personal gain; trading does not occur unless both parties gain. Accordingly, traders always benefit from trade and, so, are evolutionarily preferred. Analysis of the Hawk–Dove–Possessor–Trade game shows that those who trade are evolutionarily preferred over Possessors who do not. That voluntary exchange tends to improve social welfare is not new; it is already well known from traditional Walrasian analysis. What is new here is that, *without the help of rationality or utility maximization, evolution is enough by itself to generate trade*.

This raises the question, if trade is evolutionarily preferred over possession without trade, why do not Gilbert's butterflies in Section 1 trade?[11] Why does not an animal with extra food barter away some in exchange for a future meal? To be sure, this does occur in a rudimentary way when animal family groups hunt together in cooperative packs and share prey. But it is probably fair to say that animals do not trade with strangers unless the exchange is immediately mutually gratifying (as in the cleaning fish example).

The main barrier to animal trade is probably logistical and traces back to the exchange value x in the Hawk–Dove–Possessor–Trade game. The existence of x tacitly presumes

[11] To be more precise, there is no evidence to suggest that butterflies trade. However, we cannot rule out the possibility that they do trade. Other species exhibit a rudimentary form of trade biologists call "mutualism." Cleaning fish, which eat debris off the bodies of bigger fish, trade their cleaning services for food (Maynard Smith, 1982, Chapter 13).

a form of book keeping, either mental accounting or the use of money. Money has not evolved in the animal kingdom and, absent money, anonymous trading is difficult because unrelated animals cannot keep track of who owes who how much. Hence, the failure of animals to evolve a monetary system probably has obstructed the emergence of animal trade from animal territoriality instincts. But why has money not evolved in animal kingdoms? Perhaps, like law or other sociopolitical structures, money is higher up in the evolutionary path, and it emerges only along with human (or prehistoric human) traits such as language and agriculture.

Beyond property rights, can evolutionary games explain the origin of other human social norms? An affirmative answer requires two ingredients: a theory of the origin of social norms, and an identification of the specific evolutionary games corresponding to each norm. This article has illustrated how to realize the second of these two ingredients by constructing the games corresponding to the practice of possession and trade. Let's now turn to the first.

For an evolutionary theory of social norms, it is unlikely that human social norms are biologically evolved like butterfly territoriality is. Rather, the allusion to biological evolution must be metaphorical. In biological evolution, genes undergo natural selection in an ecology of water, geology, food, and weather. To survive, genes and their organic manifestations must adapt, mutate, and establish parasitic, predatory, or mutualistic niches in the food chain. Natural selection of the fittest weeds out inappropriate genes. In the long run only genes which manage to stake out biological niches in the food chain reproduce and propagate.

Norms are the "genes" undergoing natural selection. Through their embodiment in the behaviors of their human carriers, norms compete against each other for social popularity against a backdrop of cultural traditions and legal and political institutions—themselves manifestations of successful ideas. Not unlike between genes in biological evolution, the competition between norms for social acceptance and influence is a life and death struggle. Those that do not successfully adapt across time and sociopolitical barriers die.

This notion that norms are like genes is not new. In *The Selfish Gene*, Dawkins (1976) proposes that social ideas, what he calls "memes," are a non-organic form of life. His examples of memes include tunes, catch-phrases, taboos, and architectural fashions. In Dawkins' view, the fundamental characteristics of life are replication and evolution. In biological life, genes serve as the fundamental replicators. In human culture, memes are the fundamental replicators. Both genes and memes evolve by mutation-coated replication and natural selection of the fittest. Analogous to how genes encode the essence of biological life, Dawkins regards memes as genetic carriers of a memotic life form—what we know as human culture. This theme has found popularity in several fields (Waldrop, 1992; Wilson, 1975; Yee, 1997).

Epstein's theory (1980) of evolutionary norms goes beyond Dawkins' by incorporating a sociobiological dimension. The thrust of Epstein's hypothesis is that human beings who abide by certain rules of conduct are more likely to survive, reproduce, and pass on both biological genes *and* ideological memes to their children. Over generations, natural selection operating at a *combined* biological and cultural level leads to ingrained behavioral traits. Epstein listed four categories of law which he thinks has evolutionary roots: (i) prohibition against violence except in self-defense; (ii) first possession as the root of title; (iii) obligations of parents to their offspring; (iv) promissory obligations.

A cross between Dawkins' memes and Epstein's theory of sociobiological enhancement is compelling. In this picture, less successful individuals and groups within a population must imitate the behavior of their more successful peers in order to successfully compete for resources. Accordingly, the more above average an individual is, the more others copy his behavior. As a result of peer mimicry, the population establishes and self-enforces over time standards of normal behavior. Normal behavior may either be time-independent or it may cycle through a range of behaviors. This picture is naturally reconciled with evolutionary games because the evolutionary process is essentially a scenario of replication dynamics based on survival of the fittest. Any process which favors iterated, merit-based growth of some subgroups at the expense of peers—such as Darwinian evolution or proportional group learning—can be described by evolutionary games.

The appeal of evolutionary games is that participants do not have to be endowed with superhuman characteristics like unfailing Bayesian rationality. Even butterflies and baboons are qualified to play. All that is asked is that the parties learn by trial and error, incorporate what they learn in future behavior, and die if they do not.

This article also raises another question, What is the connection between norms and formal law. The Possessor and Trade ESSes suggest only that these ownership conventions may emerge as social norms—they do not draw any connection between norms and formal law. Indeed, Ellickson (1991) suggests that not only are fundamental norms like neighborly cooperation pervasive but they exist *independently of and oblivious to* legal standards. Based on a case study of ranchers in Shasta County, California, Ellickson conjectures that the omnipresent threat of reputation-damaging gossip is an effective means of enforcing social norms in the Shasta County ranching community without the need of laws. So why laws?

If law is not necessary to sustain Trade in Regions II or III of Fig. 4, is the (only) role of law to guide society into (or out of) these two regions by twiddling cost h with the exaction of penalties?

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