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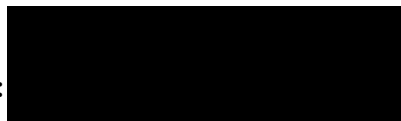
[1]Why Nature and Science are both negative.

[OR: [2] Is it better to reward or punish?]

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Machiavelli^{1,2} felt that punishments were more effective than rewards. However, Machiavelli's explanation is unconvincing: "...the bond of love is one which people, base creatures that they are, break when it is to their advantage; but fear is strengthened by a dread of punishment which never fails". This conclusion is paradoxical because rewards and punishments with equal fitness ratios will seem equal to recipients, which should quickly evolve to perceive these ratios. In natural selection, it is the proportional, rather than the absolute fitness that is important³.

The Machiavellian principle is easier to understand, at least in Nature, by considering donors' costs. Rewarding is costly - the cost of giving fitness away will increase in proportion to the benefit of receiving it. Donor's costs of punishment will also increase with the damage to recipients¹ - fighting an opponent may entail a risk of injury or even death. Donors, however, can severely damage recipients, for example by killing or sterilizing: if the recipient's fitness is represented by $(1+s)$ or $(1+t)$, where $-1 < s, t < +\infty$ represent the benefit (or, if negative, loss) to the recipient, it is possible for the donor to deliver a punishment of $s = -1$, causing zero fitness for the recipient. Animals can and do kill their opponents¹. To donate an equivalent reward for good behaviour would be impossible; this would require $t = +\infty$; effectively a donor must provide the recipient with the opportunity for infinite numbers of offspring, because the recipient's proportional fitness change is the same whether given a reward worth $(1+t)/1 \mid t \rightarrow +\infty$ or a punishment worth $1/(1+s) \mid s \rightarrow -1$. It will be simply impossible for a donor to provide a reward with persuasive effect equivalent to a very strong punishment. When the fitness ratio needs to be large - either to reward major abstinence or to punish major infractions - it will be better to punish. If the punishment or reward is small, then, because $[(1+t)/1 \approx 1/(1+s)] \mid (-s = t) \rightarrow 0$, the costs of doling out equivalently small punishments and rewards are likely be more similar.

Therefore, infractions with potentially major fitness effects - attempting to take over a dominant male's harem, for instance - should usually be punished. In contrast, coercion to avoid minor transgressions - in struggles to get an unfair share of mother's teat during a single

feed, for example - might use reward or punishment because costs to the donor will be more nearly symmetrical. This is only the simplest analysis: in practice, giving mates or food may often be about as costly to donors as it is beneficial to recipients, whereas inflicting punishment will often cost a dominant animal much less than the loss inflicted. So things look very bad indeed for rewards. Cheating⁴ will not affect this argument because the probability of avoiding detection will be the same whether coercion is via punishment or non-payment of a reward. To conclude, Machiavelli hit on a simple and fundamental asymmetry between reward and punishment when costs, losses, and benefits are great (he studied Cesare Borgia, let us remember).

[This Machiavellian asymmetry is unlikely (I hope) to be employed in human justice, regardless of Machiavelli's original intent. Our behaviour evolves culturally as well as genetically, and cultural "costs" and "benefits" are complex. In any case, evolution is an extremely dubious basis for ethics. However, the Machiavellian principle is very general in evolutionary systems, for instance in Science. Popper⁵ showed that a single set of data which destroys a theory (falsification) is as important as an infinitude of observations which agree; this is simply Machiavelli's principle applied to the evolution of scientific knowledge. The structure of strong natural selection ensures that both Nature and Science work best negatively.]

<- *Optional paragraph.*

1. Clutton-Brock, T.H. & Parker, G.A. *Nature* **373**, 209-216 (1995).
2. Machiavelli, N. *The Prince* (privately published, San Casciano, ca. 1514).
3. Haldane, J.B.S. *The Causes of Evolution*. (Longmans, London, 1932).
4. Trivers, R. *Social Evolution* (Benjamin Cummings, Menlo Park, 1985).
- [5. Popper, K. *Objective Knowledge. An Evolutionary Approach*. (Oxford University Press, Oxford, 1972).] <- *If last para cut, omit this, and use title 2*