Research Article

Ratio Versus Difference Optimisation in Human Behaviour

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Models of optimization have played an important role in the fields of evolution as well as economics. In the classical models of optimization, some tend to maximize the ratio of returns to investment, and others tend to maximize the difference between the two. Clarity in the contextual appropriateness of the ratio versus difference model came very recently. This clarity resolves several questions, paradoxes, and apparent fallacies in animal behaviour as well as in human social and economic behavior. Phenomena such as the offspring quality-quantity trade-off apply to human behaviour by principles similar to animal behaviour. Paradoxical phenomena such as the concord or sunk cost fallacy, the differential acceptance of high-yielding varieties in agriculture versus livestock, and the differential strategies of harvesting natural resources are better understood by ratio and difference optimization conditions. The human mind might have evolved an innate knowledge about when to use the ratio or difference model in decision making.

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A theory of optimality in decision making has been discussed in ecology as well as economics for several decades. Parker and Maynard Smith[1] summarized prior work and articulated the concept as applied in behavioral ecology. These optimization models typically consist of an objective beneficial outcome that comes at a cost. The relationship between the cost and accrued benefit is non-linear, often following a saturation curve. Parker and Maynard-Smith discussed many examples of optimization models, in some of which the difference between investment and returns is maximized and in others the ratio of the two is maximized[1]. However, why it is appropriate to use the ratio in some examples and the difference in others was not explained. This ambiguity remained in optimization literature for quite a long time. The outcome of optimization using a ratio or using a difference can be substantially different, often diametrically opposite, was pointed out relatively recently, and a set of rules as to when a ratio model is appropriate and when a difference model was discussed by[2][3][4].

It can be shown that in an atypical scenario with the returns having a saturating relationship with the investment (Figure 1), in a profitable deal, a ratio optimum typically lies to the left of the difference optimum[2].

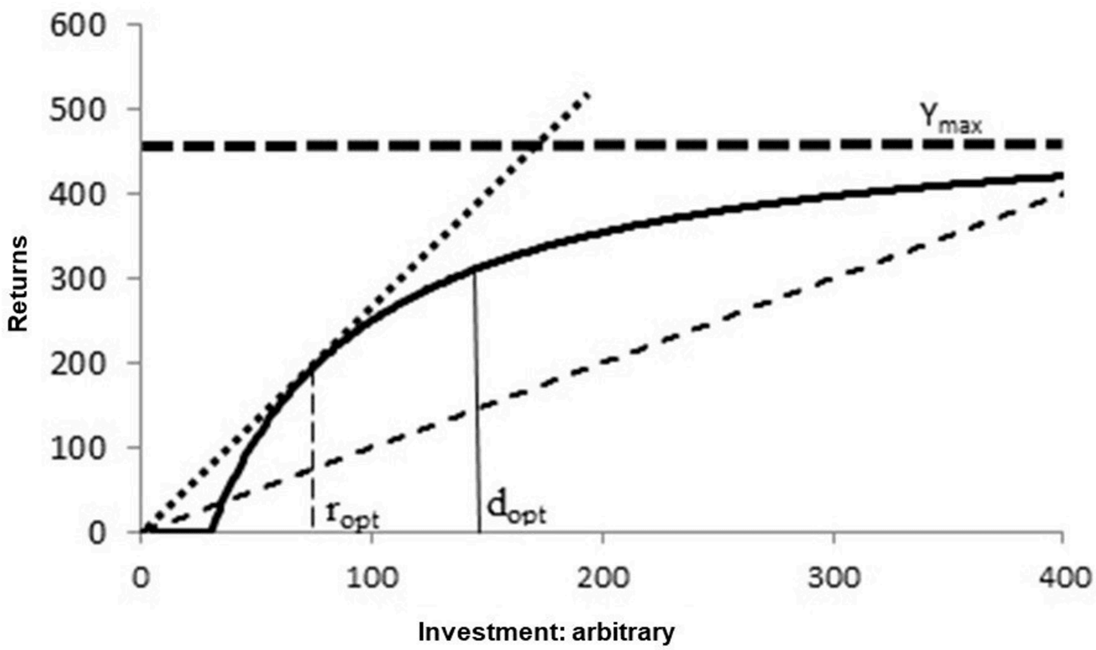

Figure 1. A schematic representation of the ratio optimum r_{opt} and the difference optimum d_{opt} when the returns follow a saturating relationship with the inputs[3].

In other words, a ratio optimizer would be keener on cutting costs since reducing the denominator is the most effective strategy for maximizing the ratio. In contrast, a difference optimizer does not mind increasing the cost if the resultant benefit increases at least slightly more than the cost increment. These models show that a ratio model is appropriate when the investible amount is limiting but not investment opportunities. In contrast, when the investment opportunities are limiting but not the investible amount, a difference model is appropriate[2][3][4]. While this principle has been applied to many problems in behavioural ecology[2], its implications for human behavior and economic decisions remain underexplored. We attempt to explore some of the possibilities here.

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According to these models, if c_0 is an initial overhead cost necessary before returns begin, then the returns *Yc* obtained at a cost *c* are assumed to follow the equation,

For $c>=c_0$

$$Y_c = \frac{Y_{\max}(c - c_0)}{K + (c - c_0)} \qquad \text{(Equation 1)}$$

Where Y_{max} is the maximum possible returns to which the curve shows an asymptotic relationship and *K* is the half saturation constant[2][3].

With this assumption, the running cost (in addition to c_0) that maximizes the ratio turns out to be[2][3]

$$cs_{(ropt)} = \sqrt{c_0 K} \qquad \text{(Equation 2)}$$

And the running cost that maximizes the difference is given by

$$cs_{(dopt)} = \sqrt{K.Y_{\max}} - K \qquad \text{(Equation 3)}$$

From equations 2 and 3, it can be concluded that the ratio optimum is dependent on the overhead cost c_0 but not on Y_{max}. In contrast, the difference optimum depends upon Y_{max} but not the overhead[2].

Implications for human behavior

Since social and economic decisions are to be taken in a variety of contexts with different limiting factors, humans are expected to use ratios and difference models in different contexts. The question is whether people intuitively know the appropriate use. We illustrate below using multiple examples how people use ratio models in some contexts and difference models in other contexts. Very often, they use the right model in the right context. Examples of contextual optimum behavior are noted in animals[5][6][7][8], plants[9] and even bacteria[10][11][12]. Therefore, it may not be a surprise if they have also evolved and are innate to human decision making. But we also see that at times there is a mismatch between the context in which the optimization mechanisms might have evolved and the context in which it is being used today, and that leads to ecologically or economically irrational behavior.

1. Concorde fallacy:

   Concorde fallacy or sunk-cost is a long-standing conundrum. Even when it was clear that the Concorde airplanes would not bring any profit, the British and French airlines continued using them on the grounds that they had spent a large amount of money on recruiting them, which should not go to waste. Continued use of these planes constitutes economically irrational behavior. There are examples of Concord fallacy or sunk cost fallacy in animal as well as human behavior[13][14][15][16]. We propose here that the apparent paradox can be understood based on the ratio versus difference model.

An airline company can potentially recruit any number of planes. So, the limiting factor is not the number of planes but the amount that the company decides to invest. By this consideration, if the project was perceived to be profitable, the ratio model would have been the appropriate optimization strategy. In the economics of launching a new batch of planes, the cost of manufacturing, recruiting, and training would have been c_0 of the model. In the phase of actual use, the running cost would be directly proportional to the number of passenger voyages made. The returns, however, need not increase linearly and may be assumed to follow a saturation curve. The returns with maximum capacity utilization should be Y_{max} of the model. However, if the demand is consistently lower than the capacity, Y_{max} will be proportionately lower. Note that the optimum investment in a ratio model is independent of Y_{max} by equation 2. So, when the actual returns turned out to be much lower than the expected (Figure 2), for ratio thinkers, the intended duration of use would not change.

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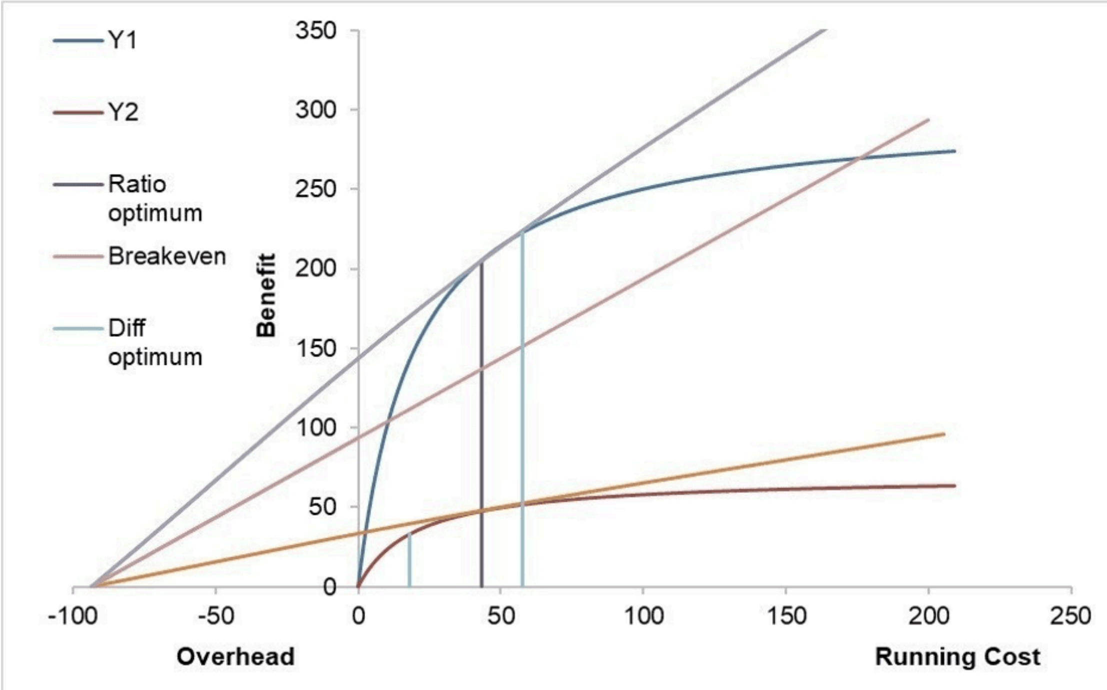

Figure 2. The ratio versus difference optima in a concord fallacy scenario. When the actual returns Y2 are substantially lower than the expected returns Y1, the ratio optimum does not change, but the difference optimum shifts to the left.

- The difference optimum, on the other hand, would reduce substantially if the curve fails to rise as expected. Therefore, a difference optimizer would advise termination of the use of the planes as soon as the slope of the curve becomes less than unity. The ratio optimizer, on the other hand, would continue until the originally projected optimum use. So, the continued use of Concorde despite absolute loss is not irrational for a ratio thinker. However, for a difference thinker, it is indeed a fallacy.

2. Mother's investment in offspring: In a rural Ethiopian community, technological intervention to reduce the physical stress of mothers was expected to increase the health status of mothers along with improved child health. However, in reality, fecundity and birth rate increased in response to the intervention, leading to further worsening of child nutrition[17]. A simplest and most appropriate explanation is offered by understanding whether the mothers were optimizing the ratio or the difference. The offspring quality-quantity tradeoff is a well-known trade-off in evolutionary ecology, which is shown to be mathematically equivalent to the ratio-difference

model dichotomy[2]. In a community of ratio optimizer parents, if an intervention saves mothers' efforts in day-to-day work, it is equivalent to reducing c_0 in the above model. Reducing c_0 in a ratio model reduces the optimum investment per unit by equation 2. Mothers in this community appear to have done the same. If this intervention were preceded by effective birth control measures, the optimization would have shifted to the difference model. Then the maternal investment per child would have increased. Here, the health workers had a difference optimization model in mind, but the context favored ratio optimization, and the population could be intuitively following it. This mismatch led to unexpected and undesirable results of the intervention.

3. Optimization in agriculture versus animal keeping: Watve & Ojas[4] pointed out that in the Indian traditional sustenance agricultural practice, a farmer typically possesses only one farm. This is a context in which the investment opportunities are limiting. Therefore, a farmer should use a difference optimum for investing in a farm. In contrast, in traditional animal keeping, where animals are grazed in a common grazing land, the number of animals is unlikely to be limiting[18]. Therefore, a ratio model is more appropriate for investing per animal. If animals are allowed to breed naturally, the overhead cost per animal is also small. Therefore, traditional animal keepers using common grazing grounds are expected to be ratio optimizers. Although we are using the words farmers and animal keepers, it will not be a surprise if the same individuals use distinctly different economic models in agriculture and animal keeping. This distinction may not be recognized at a conscious level.

   The hypothesis that farming is a difference optimization economics and animal keeping is ratio optimization economics, and people use the right model in the right context has testable predictions. The model shows that increasing c_0 does not alter the further investment in a difference model, but increases it in a ratio model. We can expect, therefore, that a higher cost of land would not make any difference to the farming practices, fertilizer use, etc., whereas a more costly animal breed would receive greater inputs in terms of feed quality, veterinary care, and other measures. Although this is anecdotally true, systematic data to test this prediction is needed.

   The difference between the thinking of farmers and animal keepers might be reflected in the differential response to hybrid seeds versus crossbred cattle in India. Both promise an increased output but at a higher cost. The difference optimizing farmers appear to have accepted the high-cost high returns practice. In contrast, animal keepers, being ratio optimizers, were keener to keep the denominator small and therefore gave a cold response to cross-breeding and artificial insemination programmes[4]. On the other hand, farmers gave a limited response to the zero budget natural farming practices. Although widely varied claims have been made about its performance and yields[19][20], it was promoted mainly on the grounds of saving cost and avoiding debts[21][22], which was apparently not found too attractive by most farmers.

The economics of animal keeping changes with private pastures/ranches. If the owner has sufficient investment capacity and the animals are to be grazed on their own land, the pasture land becomes the limiting factor. Limited and exclusive pasture land puts an upper limit on the number of animals and makes it an opportunity limited case. So, for private ranches, a difference model becomes more appropriate over a ratio model. We expect that the care per animal and thereby the productivity per animal will increase with the privatization of pasture land. Selective breeding for high productivity animals is expected to be boosted by the privatization of pasture lands. In contrast, in common grazing land systems, even genetic intervention will have a limited effect on productivity because this is a ratio optimization system. In the long run, selective breeding of cattle in a ratio optimization economics will select for animals more resistant to disease and resilient to environmental fluctuations so that the cost of animal care is minimized. In difference optimization economics, animals with greater productivity will be selected, even if they need a greater cost of maintenance.

Similarly, the economics of agriculture is likely to change if farmers have several simultaneously running alternative modes of income. If one or more family members are employed and contribute to the family income, a retired individual with substantial savings takes to farming, a tribal family dependent on non-timber forest products (NTFPs), or a pastoral community mainly dependent on animals takes to seasonal farming, and thereby the farming income is only a small part of their economics, then they may turn ratio optimizers. Such individuals are more likely to turn to fully organic farming, zero budget natural farming, indigenous seed conservation, and such practices that are appropriate for ratio optimization. This is also a systematically testable prediction by examining the socio-economic and familial background of organic farmers in comparison with others.

Another important implication of the ratio-difference model in social welfare and poverty alleviation is in selecting the right kind of aid for long-term effects. Distributing livestock of a high yielding breed is a common means of aid to the poor[23][24]. Many of them end up with very limited success[25][26]. One can ask whether donating animals is the best way to aid the community or if there can be better strategies with equal monetary inputs. Donating animals would reduce c_0. In a ratio model, this would tend to shift the optimum and thereby the productivity to the left, independent of $Y_{max.}$ Therefore, the beneficiaries are unlikely to invest sufficiently in taking care of the animals. On the other hand, if the cost of taking care is decreased, the curve rises more sharply, resulting in a higher productivity of the animal per unit cost (figure 3). The assumption of this prediction that individuals use a ratio model and have innate algorithms of optimization can be experimentally tested in this context.

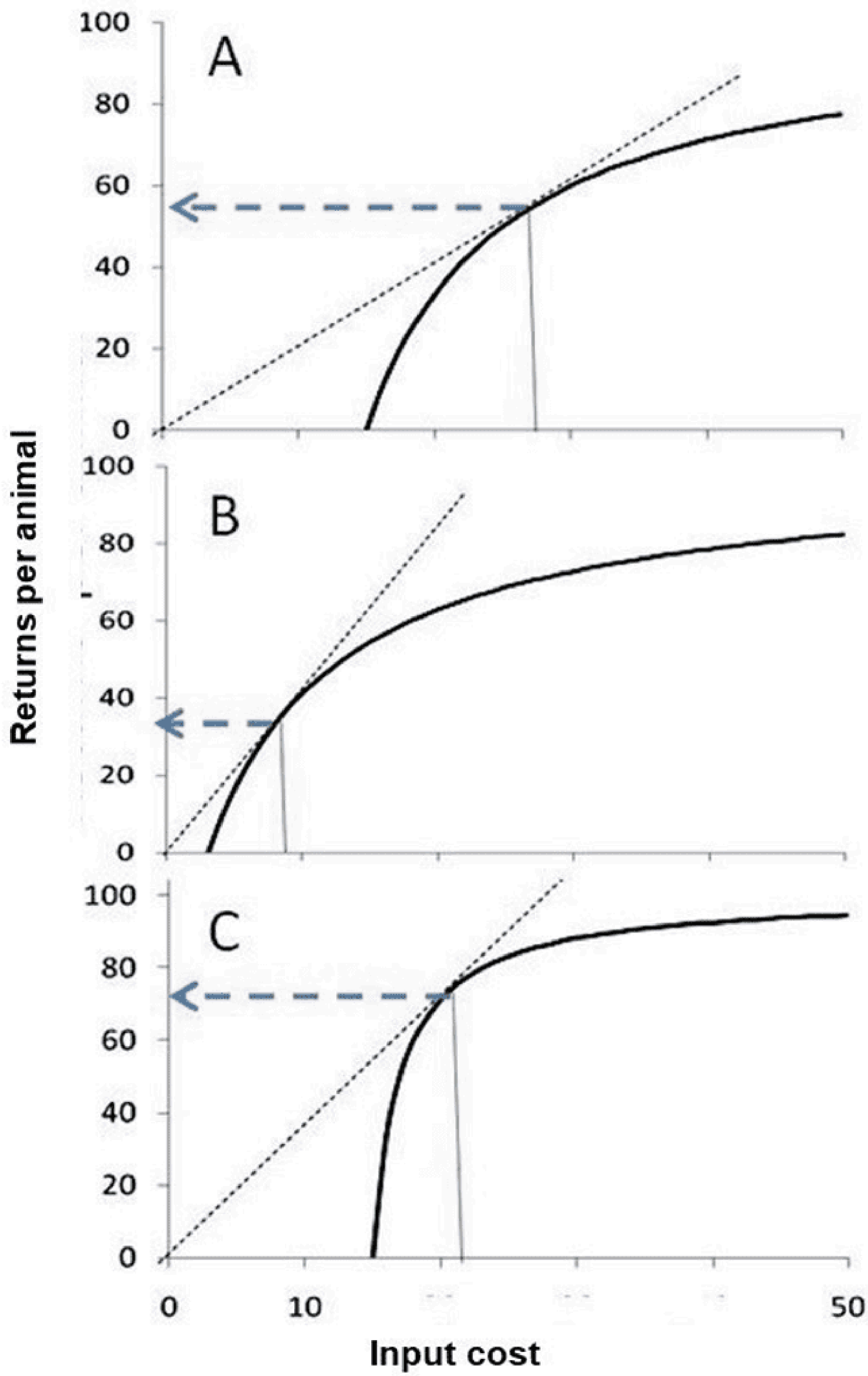

Figure 3. Effects of different kinds of aids on the optimum care and productivity per animal (A) The cost benefits of animals without aid (B) If animals are distributed free or subsidized heavily,

$\mathbf{c_0}$ decreases and the optimum shifts to the left, and productivity per animal reduces (C) If animals are not subsidized but the cost of care is, the curve rises more sharply, and the animal productivity at the new optimum is higher as compared to A and B. This makes a testable prediction for experimentally testing the hypothesis that people innately use a ratio optimization model.

- If two randomized groups are made, one of which receives the animals at substantial subsidy and the other does not get a subsidy on animals but gets an equivalent amount of subsidy on the feed, veterinary care, and other essentials in animal care. The model expects that the second group will show substantially greater productivity per animal than the first one. It is possible to test the hypothesis of innate knowledge of economic models using an experimental economics approach.

4. Sustainable collection of seasonal natural resources: For people living in natural habitats and depending on multiple natural resources for livelihood, sustainable harvest is important for the long-term stability of livelihood resources. We expect the success of collection to follow a saturation curve with increasing efforts. For a given resource, the crucial question is when to stop harvesting one resource in each season. If there are multiple options for livelihood, the decision would be ratio-based. If there are limited alternatives for livelihood, the decision would be difference-based. A ratio-based decision spares a greater proportion of resources for regeneration. A difference-based decision is likely to result in overharvesting. The tragedy of the commons[18] is more likely to happen if the habitat has fewer options or if the society has specialized communities monopolizing different resources. The latter is seen in many societies such as the traditional Indian endogamous communities with niche partitioning. For such communities, overharvesting is likely to be a potential hazard. However, since the community has little alternatives for livelihood, they need to assure sustainability, and this is often achieved by making prudent harvesting norms for the community[27][28]. For communities having a wide variety of livelihood resources, strict harvesting norms need not evolve, and sustainability is still assured because they follow a ratio optimization model and thereby limit their harvesting to a lower threshold.

Although the dynamics of natural resource harvesting have been a focus of investigation, studying the behavior of different communities dependent on natural resources in the light of ratio-difference strategies is likely to be both challenging and insightful. From the examples discussed, the ratio versus difference dichotomy can have implications for understanding human behaviour in several contexts. The outcome of a developmental intervention can be affected by whether people view it with a ratio or difference model[4]. Further, people's perception of risk also depends upon whether they perceive risk as a ratio or difference between probabilities of a disaster[29]. Watve[30] further argued that the biases in peer reviews can also arise from the innate ratio-difference based decisions of editors and reviewers. There can potentially be many more examples where human decision-making can be better understood with clarity on whether the ratio or the difference is being used for optimization.

Behavioural economics and behaviour-informed policy making are rapidly upcoming branches of science[31]. So far, system designs and policy making have not considered people's innate economic models. An understanding of the appropriate optimization model in any context can be the key to the success of any law, welfare policy, or system design for any purpose. The principle we described is the beginning of a potentially promising line of research that might help increase the success of welfare schemes for people.

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Conflicts of Interest

The authors declare that they have no competing interests.

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