Ratio versus difference optimization in human behavior

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Abstract

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 net benefit or the difference between the two. Clarity in the contextual appropriateness of the ratio model versus difference model came very recently. This clarity resolves several questions, paradoxes, and apparent fallacies in human social and economic behavior. The human mind might have evolved to carry an innate knowledge about when to use ratio and when to use difference model in decision making.

Keywords: Optimization, concord fallacy, human behavior, maternal investment, sustainable harvest

Introduction

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 law of diminishing returns. 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 difference in others was not explained. This ambiguity remained in optimization literature for quite long. The outcome of optimization using ratio or using 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 Watve et al[2], Watve and Ojas[3] and Shinde et al[4].

It can be shown that in a typical 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[4]. 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[2-4]. While this principle has been applied to many problems in behavioural ecology[4], its implications to human behavior and economic decisions remain underexplored. We attempt to explore some of the possibilities here.

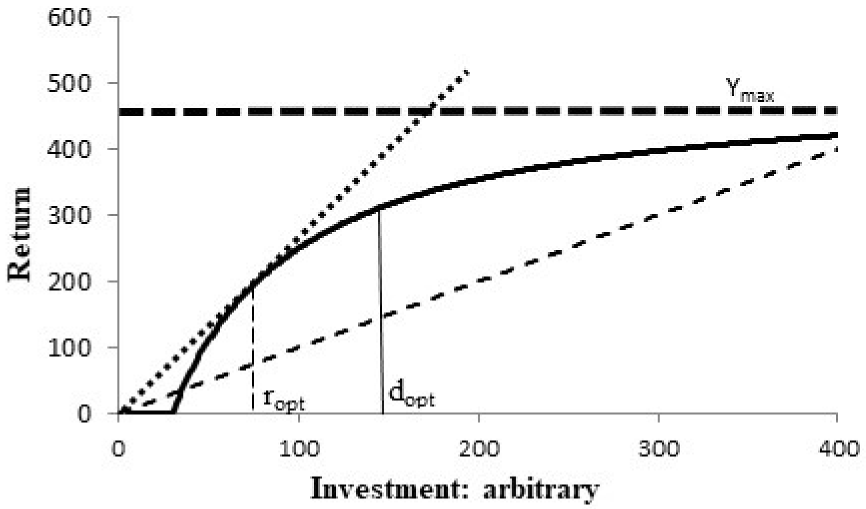

Figure 1: A schematic representation of ratio optimum r_{opt} and difference optimum d_{opt} when the returns follow a saturating relationship with the inputs.

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 $c >= c_0$

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

Where Y_{max} is the maximum possible returns to which the curve shows an asymptotic relationship and *K* is the half saturation constant[2,4].

With this assumption, the running cost (in addition to c_0) that maximizes the ratio turns out to be[2,4]

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

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[4].

Implications to human behavior:

Since economic decisions are to be taken in a variety of contexts with different limiting factors, humans are expected to use ratios and difference in different contexts. The question is whether people intuitively know when to use ratio and when to use difference. This question is crucial since within optimality theoreticians this clarity was absent until recently. 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[5–8], plants[9] and even bacteria [10–12]. Certain behavioral mechanisms evolved by natural selection presumably enable optimum decisions in non-human life forms. Therefore it may not be a surprise if they have also evolved and are innate to human decision making. It may not be a surprise if people use the right optimality model in the right context, even when academia were yet to discover these principles. 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 waste. To discontinue using them would have avoided further net losses. Continued use of these planes constitutes an economically irrational behavior. There are examples of Concord fallacy or sunk cost fallacy in animal as well as human behavior[13–16]. We propose here that the apparent paradox can be understood based on the ratio versus difference model.

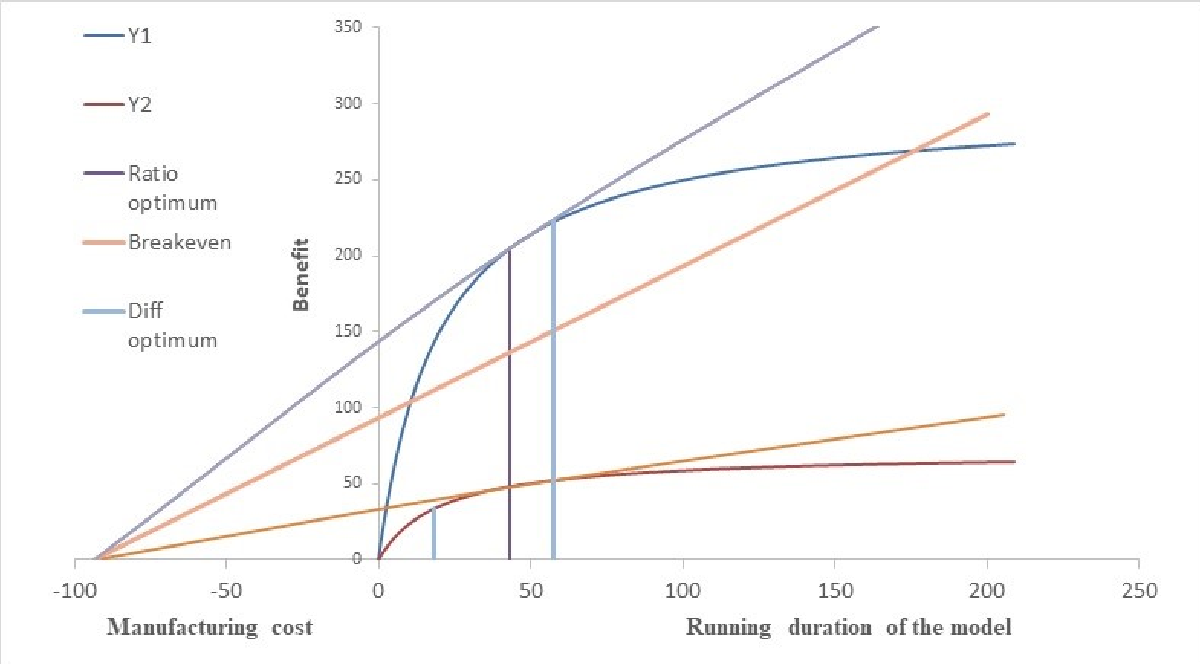

Figure 2: The ratio versus difference optima in a concord fallacy scenario. When the actual returns Y2 are substantially lower than the expected returns Y1, the ratio optimum does not change but the difference optimum shifts to the left.

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, 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 revenue curve turned out to be much lower than the one projected (Figure 2), for ratio thinkers the intended duration of use would not change. 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 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 till the originally projected optimum use. So, the continued use of Concorde despite absolute loss is not entirely irrational. It is a different consideration. If a ratio model is indeed appropriate for the context, then it is not a fallacy. However, if a ratio model is being used when it should have been a difference model, it is indeed a fallacy.

The animal and human examples of sunk cost behavior need to be re-examined for the appropriateness of the ratio model for the context. It is likely that the innate behavior is based upon a ratio model but we are interpreting the decisions assuming difference models and the lack of clarity between the contextual appropriateness of the two models makes it appear as 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 this intervention leading to further worsening of child nutrition[17]. A simplest and most appropriate explanation is offered by understanding whether the mothers were optimizing ratio or difference. Offspring quality-quantity tradeoff is a well-known trade-off in evolutionary ecology which is shown to be mathematically equivalent to ratio-difference model dichotomy[4]. 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 difference model. Then the expectation of the health workers would have come true that maternal investment per child would increase and thereby child health. Here, inadvertently the health workers had a difference optimization model in mind, but the context favored a ratio optimization and the population could be intuitively following it. This mismatch led to unexpected and undesirable results of the intervention.
3. Business optimization: Watve & Ojas[3] 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. 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 accepted the high-cost high returns practice. 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[3].

The economics of animal keeping changes with private pastures/ranches. If the owner has sufficient investment capacity and the animals can only to be grazed in 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 ratio model. In the difference model, animal keepers are keener to invest more per animal but expect greater returns. By this consideration the animal husbandry practices would change according to the model. We expect that the care per animal and thereby the productivity per animal will increase with privatization of pasture land. In an open grazing system, the total productivity will depend more on animal numbers than on productivity per animal. A testable prediction of the model is that selective breeding for high productivity animals is expected to be boosted by privatization of pasture lands. In contrast, in common grazing land systems, even genetic intervention will have limited effect on productivity because this is a ratio optimization system. In the long run selective breeding of cattle in a ratio optimization system and difference optimization system will lead to different outcomes. 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 greater cost of maintenance.

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 long term stability of livelihood resources. In biodiversity rich areas, multiple resources are available and the availability is often season dependent. 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 and turn to alternative resources. If there are multiple options of 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 is more likely to happen if the habitat has fewer options or if the society has specialized communities monopolizing different resources[18]. 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[19,20]. For communities having 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 has been a focus of investigation, the ratio-difference distinction in optimization has not been a part of the conceptual framework in this field. 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.

Conclusions:

From the examples discussed, it can be seen that the ratio versus difference dichotomy can have implications for understanding human behaviour in several contexts. Watve and Ojas[3] argued that the outcome of a developmental intervention can be affected by whether people view it with a ratio or difference model. Further people's perception of risk also depends upon whether they perceive risk as a ratio or difference between probabilities of a disaster[21]. Watve[22] 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 in whether the ratio or the difference is being used for optimization.

So far system designs and policy making has not considered people's innate economic models. An understanding of the appropriate optimization model in any context can be a key to the success of any law, welfare policy or system design for any purpose. The principle we described is a beginning of a potentially promising line of research that might help increase the success of welfare schemes for people.

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