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Emergence of Risk Sensitivity from First Principles: an Agent-Based model

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1 Introduction

Risk aversion and risk-seeking are well-known characteristics of human and non-human behaviour. Several works show how different kinds of entities respond to risk in various disciplines, such as biology, economics and psychology. Whatever is the level of analysis, the risk sensitivities of living entities seems to be shaped by the same common fundamental principles. Specifically, the chance of taking a risky decision is affected by the variability of the possible outcomes. Individuals that favour choices with low uncertainty are considered risk-averse. The similarity of these features suggests that it could exist a regularity regarding how living entities develop risk preferences.

This work aims to show that risk sensitivity can emerge in a population from spatially explicit first principles individuals' interactions. It follows the lead of other works [**1**, **2**, **3**]. Besides, it aims at assessing the effect of environmental factors on this emergent phenomenon. The influence of the adaptation style on this relationship is studied too. We define the adaptation style as the set of techniques the populations of individuals have at their disposal to adjust their behaviour to the surroundings. Two adaptation styles are investigated: genetic evolution and individual learning (with or without transmission

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to offsprings). We pursue the purposes by developing and simulating an agent-based model in which agents can choose between a risky and a safe option. The model is simple and not empirically grounded since its goal is to find out general rules, to verify later by real-world investigations. Then, we called it a "first principles" model because it relies on basic rules without any other assumptions.

2 Methodology

A simple agent-based model is developed. The landscape of the model is a two-dimensional toroidal surface divided into squared cells. Each entity is located on a cell. Cells either contain an energy source or are empty. Initially, each fount has a certain level of energy. When agents are in proximity of a source, they can collect energy, progressively draining it. Once an energy spring is consumed, it disappears, and another appears in a different cell. Agents consume a given amount of energy at each time step. When an agent runs out of energy, it dies. Therefore, agents need to recharge to survive. There are two ways to collect energy: supply from a source or attack other agents and steal from them. Figure 1 illustrates the decision-making process.

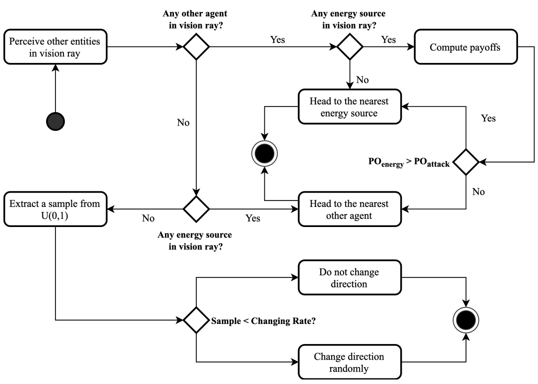

Fig. 1 Decision-making of agents in the model

Aggressions have a probability of success. A victorious agent subtracts a share of energy from the defending agent. Oppositely, a losing one gives a part of its energy to the defending agent. The model is designed to make agents deciding between these two options: a risky one and a safe one. For each possibility, agents compute a payoff, which formula is the distance from the option i times the desirability of that opportunity. Mathematically, it is:

$$PO_i = \left(\frac{v - d_i}{v}\right)[l_i * lw + g_i * (1 - lw)] \tag{1}$$

where d_i is the distance of an agent from the option i, v the maximum distance of perception, l_i the desirability of option i learned by experience, g_i the generic desirability of option i, and lw adaptation style of the population, which stands for the overall preference between a decision making driven by genetic adaptation or by cultural adaptation. The nearer the target, the higher the payoff. For $lw = 0$, decision making of agents is influenced solely by genetic adaptation. For $lw = 1$, it is determined entirely by experience. For intermediate values, decision making is a mix. Agents select the choice with the highest payoff. The outcome of the model is the risk sensitivity of the population of agents, which is defined as the difference between mean risk proneness and mean risk aversion of agents. We performed a global sensitivity analysis on the simulation model to appraise the environmental effect on the output. An analysis of the whole set of parameters was performed, since there were not preliminary assumptions about values and causal relationships.

3 Results and discussion

Simulation results showed that both risk aversion and risk-seeking behaviour emerged in the simulated model. To assess the effect of environmental parameters of this process, we developed a variation metric. It intended to measure the variation of the mean of parameters for sets of simulations with different risk preferences in the outcome. Mathematically, we define this as,

$$s = \mu_{RA} - \mu_{RS} \tag{2}$$

where μ_{RA} is the normalized mean of a parameter for the simulation in which risk aversion emerged, and μ_{RS} is the normalized mean of a parameter for the simulation in which the population of agents became in average risk-seeking. For each parameter, two scenarios were analysed, examining agents with different adaptation styles. An evolution scenario, which considered only simulations with $lw < 0.1$, and a learning scenario, including solely runs with $lw > 0.9$. We observed three cases:

1. some parameters had a direct relationship with the mean risk aversion of the population in both scenarios. All the parameters that influence the level of energy in the system belong to this category;
2. a set of parameters always had a positive influence on risk sensitivity: the higher they were, the more risk-loving the population of agents became. This set included parameters related to the expected results of aggressions. It is an awaited outcome. Logically, the adaptation process generates risk-seeking populations more often when the expected result of an uncertain decision is higher;
3. other parameters had a mixed effect. Reasons for it included the way information was processed with different adaptation styles and how different paces of life affected risk preferences in populations that learned instead of evolving by genetic transmission.

In conclusion, we examined the relationship between environmental dangerousness and the emergence of risk sensitivity (see Figure 2). We developed a dangerousness index employing an ordinary linear regression. We plotted it on the mean risk sensitivity of the populations.

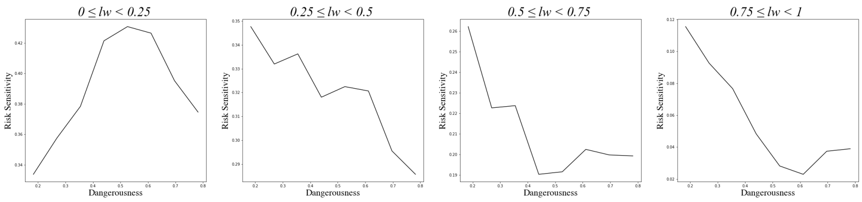

Fig. 2 Mean risk sensitivity of agents on dangerousness of the environment with regards to the adaptation style

When there is a well-defined form of adaptation, was observed a non-linear and non-monotonic relationship between environmental dangerousness and risk sensitivity. A possible explanation for it involved two concurring forces, the fitness for the environment and the expected benefit of risk-aware behaviour. When there was no risk, entities had no incentives to develop risk preferences. This incentive grew with the dangerousness of the surroundings. Oppositely, after a certain level of dangerousness, the surroundings were so perilous that being risk-averse did not change the chance of avoiding the hazard. Therefore, we proposed that the shape of the curves was the combination of these two strengths. The shape of the curve varied with the adaptation style. We assumed this distinction could be addressed to various combination patterns existing in different configurations. While literature presented comparable cases [**1**], further analysis was necessary to confirm these results.

4 Conclusions

Our work shows risk sensitivity can arise in an ABM and nontrivial relationships can occur between environmental factors and the emergence of risk sensitivity. Moreover, it explains the effect of adaptation styles on these relationships. Since the simulated model is simple, we claim these results could apply to various domains. Future development includes the validation of these findings through analysis in real-world scenarios.

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