Kinetic Market Model: An Evolutionary Algorithm

Evandro Luquini
Nizam Omar

ABSTRACT
This research proposes the econophysics kinetic market model as an evolutionary algorithm's instance. The immediate results from this proposal is a new replacement rule for family competition genetic algorithms. It also represents a starting point to adding evolvable entities to kinetic market models.

KEYWORDS
optimization heuristic, kinetic market models, econophysics of inequality, diversity, family competition evolutionary algorithm

1 INTRODUCTION
Econophysics defines itself as an interdisciplinary discipline that applies methods of physics, especially statistical mechanics, to problems of economics, finance, and other social sciences[7]. One of the main contributions made by this discipline occurs in economic inequality, where econophysicists have been developing kinetic markets [8]. Although the inspiration originates in the kinetic theory of gases, these market models are constructed using only the concepts of money and individuals replace those of energy and atoms. The atomic collision becomes a monetary transaction, in which a random pair of agents exchange a certain amount of resources guided by a stochastic rule. Using simple rules of exchange, the model evolves this artificial society to identical or similar distributions found in econometric data [1, 2]. Many of these markets reach a stationary distribution, whatever the initial population is. A steady-state arises through similar behavior observed in modern human societies: there is a progressive transfer of almost all resources to a small group or individual. Unlike the phenomenon econophysicists call condensation[3], when all individuals converge to the same state, the final distribution in those models sustains the population in the interval between none and the sum of all the resources available to society. This dynamic resembles a minimization process because it continually moves the majority of individuals to even smaller states of energy. As noted before [5], the emergence of these distributions and the dynamics of the model suggests an optimization heuristic. Despite the authors' insights, their work failed to provide an efficient algorithm. This work proposes a better solution to understand and use those dynamics recognizing the kinetic market models as an evolutionary algorithm.

2 KINETIC MARKET AS SELECTION
Econophysicists describe their models with an exchange rule, as equation 1 [4, 10]. In addition, there is a further precondition: (mi, mj) are pairs of individuals taken at random and without replacement from a population of size N in a generational style.

\[ m_i(t + 1) = \epsilon * m_j(t) \quad \text{where } \epsilon = U(0, 1) \]  
\[ m_j(t + 1) = m_j(t) + (m_i(t) - m_i(t + 1)) \]  

Described that way, the kinetic market model is identical to variations of family competition evolutionary algorithm[6], as in Fig. 1. The selection for recombination of parents (mi, mj) is not biased to the best nor does it have any access to the global state of the population. Moreover, the replacement phase allows the family to challenge only the current parents’ position, which is equivalent to the state transition from (mi(t), mj(t)) \( \rightarrow \) (mi(t + 1), mj(t + 1)). Despite the vocabulary in each discipline, the terms family competi-

![Figure 1: A schema for family competition or energy exchange.](image-url)
more abstract kinetic market model as described in 3. In this form, the model supports any evolutionary computing individuals.

\[ S = \{s_1, s_2, ..., s_k\} \text{ from } f(m_1(t), m_2(t)) \cup \{m_1(t), m_2(t)\} \quad (3a) \]
\[ W = \{w \in S | w \geq m_1(t)\} \quad (3b) \]
\[ L = \{l \in S | l \leq m_1(t)\} \quad (3c) \]
\[ m_1(t+1) = X, x \in L, P(X = x) = \frac{1}{|L|} \quad (3d) \]
\[ Q = \{q \in W | q = m_1(t) + (m_1(t) - m_1(t + 1))\} \quad (3e) \]
\[ m_1(t + 1) = \max Q \quad (3f) \]

In evolutionary computing terminology, set \( S \) is the family with \( k \) members. It has the parents \( \{m_1(t), m_2(t)\} \) and their offsprings created through recombination and mutation by \( f(m_1(t), m_2(t)) \).

More precisely, the elements in set \( S \) are the family members’ fitness. For econophysicists, it is like the asset in their market becomes the solution each agent carries or its intrinsic value.

3 AN EXPLORATORY COMPARISON

The previous motivated a comparison of the proposed model with other approaches in family competition. For this comparison, the first choice was elitist recombination. It selects the two best individuals with rules 4a, 4b. The second option selects the best individual and another random member with rules 4a, 5a.

\[ m_1(t + 1) = \min S \quad (4a) \]
\[ m_1(t + 1) = X \quad (5a) \]
\[ m_1(t + 1) = \min B \quad (4b) \]
\[ \text{where } P(X = x) = \frac{1}{|B|} \quad (5b) \]
\[ \text{for } B = S \setminus m_1(t + 1) \quad (4c) \]
\[ \text{for } x \in B \quad (5c) \]

The problem chosen for the comparison was TSPlib’s eil76. For each replacement rule, the experiment ran 10 times using a random initial population size of 100. The sampling used just the PMX operator with two configurations: the number of samples \( k=2 \) for one experiment and \( k=10 \) for another. The results are shown in Fig.2.

4 CONCLUSION

The proposed formulation had a slightly better result in both experiments. The initial data suggest that the kinetic market replacement rule was able to sustain better diversity throughout the simulation compared with the other ones, which lost it very early. In future research, the results should be subjected to a more robust statistical analysis.

REFERENCES

[1] Cerdá, J., Montoliv, C., and Colom, R. Lgem: A lattice boltzmann economic model for income distribution and tax regulation. Mathematical and Computer Modelling 57, 7-8 (2013), 1648–1655.
[2] Chatterjee, A., Chakrabarti, B. K., and Manna, S. Pareto law in a kinetic model of market with random saving propensity. Physica A: Statistical Mechanics and its Applications 335, 1 (2004), 155–163.
[3] Hayes, B. Computing science: Follow the money. American Scientist 90, 5 (2002), 400–405.
[4] Ispolatov, S., Krapivsky, P. L., and Redner, S. Wealth distributions in asset exchange models. The European Physical Journal B-Condomed Matter and Complex Systems 2, 2 (1998), 267–276.
[5] Luqini, E., and Omar, N. Rethinking exchange market models as optimization algorithms. Physica A: Statistical Mechanics and its Applications 491 (2018), 271–281.
[6] Mengshoel, O. J., and Goldberg, D. E. The crowding approach to niching in genetic algorithms. Evolutionary computation 16, 3 (2008), 315–354.

Figure 2: The optimization of TSPlib’s eil76 with the following replacement rules: the two better (BB), the best and other at random (BR) and the kinetic market (KMM).

[7] Schinckus, C. 1996–2016. Two decades of econophysics: Between methodological diversification and conceptual coherence. The European Physical Journal Special Topics 225, 17-18 (2016), 3299–3311.
[8] Sharma, K., and Chakraborti, A. Physicists’ approach to studying socio-economic inequalities: Can humans be modelled as atoms? arXiv preprint arXiv:1606.06451 (2016).
[9] Slanina, F. Inelastically scattering particles and wealth distribution in an open economy. Physical Review E 69, 4 (2004), 046102.
[10] Yakovenko, V. M., and Rosser Jr, J. B. Colloquium: Statistical mechanics of money, wealth, and income. Reviews of Modern Physics 81, 4 (2009), 1703.