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New leads in speculative behavior

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HIGHLIGHTS

- Classifying real agents into two distinct groups regarding speculation tendency.
- A minimal model of bounded rationality for artificial agents regarding speculation.
- Reproduction of theoretical predictions for perfect rationality.
- Rich phase diagrams characterizing behavior under bounded rationality.

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ABSTRACT

The Kiyotaki and Wright (1989) (henceforth KW) model of money emergence as a medium of exchange has been studied from various perspectives in recent papers. In the present work we propose a minimalistic model for the behavior of agents in the KW framework, which may either reproduce the theoretical predictions of Kiyotaki and Wright (1989) on the emerging Nash equilibria, or (less closely) the empirical results of Brown (1996), Duffy and Ochs (1999) and our own, introduced in a first part of the present paper. The main import is the systematic computer scanning of speculative monetary equilibria under drastic bounded rationality of agents, based on behavior previously observed in the lab.

1. Introduction

In the Kiyotaki and Wright [1] environment agents of three types exchange commodities in order to gain utility by consuming goods they desire. Recent studies have shown considerable interest in the KW model as explanatory to emergence of money in an economy, since goods become media of exchange. Starting with the original model constructed by Kiyotaki and Wright [1], several important discoveries have been made, following in three major directions. The first is experimentally analyzing the trading 'game' between real agents, mainly [2–4]. The second is a continued development of theoretical progress, which is based on the original analysis done by Kiyotaki and Wright themselves, such as Ref. [5]. The third is a vast field of numerical studies, where different interpretations of the KW model have been implemented and analyzed, such as Refs. [6,7] and many others which we will shortly introduce in greater detail.

The features of KW system offer a new perspective on rational decision making, since a major part of that system is the conditions which make agents determine whether to accept a loss in utility *now* for an increased chance of a higher profit *later*, which in the KW context is applied to bilateral trade.

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In other words, when do people speculate? Exploring this deep question may expand understanding in other fields besides monetary theory.

The literature cited above deals with this matter from two main angles: experimental trials and agent-based simulations. Empirical evidence of Brown [2] and Duffy and Ochs [3,4] concludes that real agents tend to speculate less than what the rational expectations of Kiyotaki and Wright suggest, so that in the overall sense real agents adopt sub-optimal behavior. Attempts to model this behavior as proposed in Refs. [8,9,7] are based on different versions of genetic algorithms usually optimizing a classifier system, or [10,11] that are based on a logistic regression of the empirical results of Duffy and Ochs [3,4].

While the classifier system is a useful tool for dealing with multi-variable optimization, in this instance it misses on two major issues. The first is that the basic KW model is a 'minimal' environment for creating an absence of double coincidence of wants[1]. It is not a complex multi-parameter setting, but rather the simplest one. Therefore, applying intricate decision making designs on artificial agents diverges from the initial purpose of the KW exercise. The second problem lies in the much too exaggerated assumption of optimal decision making of agents. Experiments such as Refs. [2–4] and our own (presented in this paper), clearly show sub-optimal behavior, and observed performance in other fields (for example: Refs. [12–14]) support this claim even further. In fact, Basci [9] has recognized this flaw, and therefore included a constant probability of 5% for taking a totally random action, within the optimizing classifier system framework. However, this gives rise to many questions such as why 5% instead of 0.5% or 15%, and why a randomization of possible actions is the appropriate way of handling irrationality.

However, regression methods are just that: they offer no causal explanation or model, only verified statistics.

In the present work we first introduce a new real-agents experimental investigation of the KW model of money emergence. This investigation, based on [3,10], has been designed to explore further the agents' sub-optimality in behaviors when interacting in a KW economy. Secondly, we introduce a new model for agents' behavior under the setting of this kind of economy. Our model, although conceptually based on ideas expressed by Basci [9], is novel in the attempt to parameterize sub-optimality in decision making, which consists as a major feature of our approach. Essentially, we formulate an imitation model which is both heuristic and 'minimal' in the sense that only a single new parameter is included.[2]

1.1. Kiyotaki and Wright (KW) model environment

Now we define the environment of the original KW model as outlined in their 1989 paper. We will refer to this setting as the 'basic', or 'original' KW model throughout the other sections.

The model includes three types of agents: I, II and III. The original setting places an infinite amount of agents, and assumes that there are equal proportions between all agents' types.

Each individual agent may carry at any time-step (which is assumed to be discrete) one and only one good. The available types of goods, or commodities, are 1, 2 or 3.

Agent of type i consume only good i, and produce good $i + 1$ modulo 3 (referred as model A).

Production costs are subsumed in the net payoff.

Utility is gained through consumption and lost through 'paying' a storage cost for holding any good. Storage cost c_i of good i depends on the type of good: $0 < c_1 < c_2 < c_3$. In the basic model, utility varies between agents of different types. However, studies such as Refs. [7,3,4] have conformed to relax that diversity and instead assume a uniform utility which is gained from consumption for all agents. This utility, u, must be 'sufficiently large' with respect to storage costs in order to become an economic drive of the entire system.

Kiyotaki and Wright introduce $\beta \in (0, 1)$ as a discount factor, which is used in calculating utility for future time steps.

At each time step, agents are paired randomly, which results in a trading encounter. A pair of agents may barter bilaterally for the goods each of them holds.

When agent i receives good i which he desires, he will immediately consume it and receive a positive utility u, and at the same time step he will produce good $i + 1$ (modulo 3) and pay its storage cost. Agents who have not consumed (and produced) during a time step only pay the storage cost for holding the good with which they are left at the end of that time step.[3]

A 'strategy' is defined as $\tau_i(j, k)$, and is assumed to be 1 if agent of type i is willing to trade good j for good k. Trade occurs only through mutual agreement, namely that if agent i holding good j meets agent h with good k, they exchange their goods if and only if $\tau_i(j, k) \cdot \tau_h(k, j) = 1$. To determine equilibrium payoffs, hence strategies, the writers characterize by $p_{ij}(t)$ the proportion of agents of type i holding good j at time-step t.

Kiyotaki and Wright study the Nash equilibrium states in the ensuing system from a mathematical perspective—personal utility at the 'end of time'. Nash equilibrium in this context becomes a stationary inventory distribution among all agents, and stationary trading strategies. Explicitly, all p_{ij} and all $\tau_i(j, k)$ reach a steady state. From that steady state no single agent, in theory, may improve his own utility by adopting any other strategy, and thus equilibrium is reached. If so, each such equilibrium would be defined by: (a) the conditions enforcing it, (b) the strategies $\tau_i(j, k)$ assumed by all agents and (c) the

1 The situation where the supplier of good A wants good B and the supplier of good B wants good A.

2 Or three parameters, in case for some reason one wishes to introduce varying degrees or sub-optimality to agents of different types.

3 Agents of type i may exchange good $i + 1$ for good $i + 2$.