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Agent-based model for rural–urban migration: A dynamic consideration

Ning Cai [a,*], Hai-Ying Ma [b,*], M. Junaid Khan [c]

[a] College of Electrical Engineering, Northwest University for Nationalities, Lanzhou, China
[b] College of Economics, Northwest University for Nationalities, Lanzhou, China
[c] PN Engineering College, National University of Sciences and Technology, Islamabad, Pakistan

HIGHLIGHTS

- A dynamic agent-based model is constructed for rural–urban migration.
- It conforms to the typical dynamic linear multi-agent systems model.
- Consensus of certain variable could be harmful to the overall stability and should be avoided.

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ABSTRACT

This paper develops a dynamic agent-based model for rural–urban migration, based on the previous relevant works. The model conforms to the typical dynamic linear multi-agent systems model concerned extensively in systems science, in which the communication network is formulated as a digraph. Simulations reveal that consensus of certain variable could be harmful to the overall stability and should be avoided.

1. Introduction

The economic growth in developing countries almost inevitably leads to substantial flow of the labor force between rural agriculture and industries in cities [1]. Many economic models have appeared since 1950s to expound the population migrations. Among them, the most famous and successful model was developed by Harris and Todaro [2], paying attention to the expected income differentials between the two sectors.

Conventional economic theory cannot interpret all the phenomena about the reality of population migration [3–5]. Possibly, this is in part because that the real labor market is a sophisticated large-scale dynamic system, with vast feedbacks and emergencies, and it can hardly be depicted by any simple structure. The macroscopic dynamics of economics are formed from the local interactions of individuals, whereas the macroscopic dynamics would in turn impact the microscopic behaviors of individuals.

Since the last decade, agent-based computational economics (ACE) have aroused extensive interest from the academic community, which is based on a new bottom-up modeling methodology. Such a methodology actually integrates the notion of complex dynamic systems into economics. So far, several articles have arisen in the literature being relational to the

* Corresponding authors.
E-mail addresses: caining91@tsinghua.org.cn (N. Cai), lxmahaiying8888@163.com (H.-Y. Ma).

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study of rural–urban migration with ACE methods. For instance, Van Dyke Parunak et al. [6] earlier discussed agent-based modeling of rural–urban migration. Tesfatsion [7] conducted experiments to study the hysteresis effect from communication networks. Silveira et al. [8] built an effective statistical mechanics model based on probability theory and ACE methods. Itoh [9] developed a scheme for the dynamic control of urbanization. Kniveton et al. [10] endeavored to predict population migration with considering the environmental influences. Filho et al. [11] proposed an evolutionary agent-based schema to simulate migrations, concerning the possibly high-order dynamics. Most of these results are empirical, lacking in-depth theoretical analysis.

The current paper is primarily devoted to extend the layout in Ref. [8] via developing a dynamic multi-agent model for the sake of simulating the rural–urban migrations.

The motivation of this work partially emerges from our explorations [12–16] of theory on dynamic multi-agent systems in systems science, especially the consensus problem. Consensus of a system implicates asymptotic stability in certain information, and it actually plays the role as equilibrium of isolated dynamical systems [12–14]. Due to its theoretical significance, the consensus problem has received extensive concern from various perspectives; see Refs. [12–23] and references therein. Particularly, a general framework of the consensus problem for first-order systems is initially proposed in Ref. [17]. A necessary and sufficient condition for consensus of linear time-invariant (LTI) first-order systems is given in Ref. [18]. Consensus problem of high-order systems is earlier addressed in Refs. [19,20]. Both observer-based dynamical protocol and robust consensus are handled in Ref. [21]. A noteworthy approach about oblique decomposition of the state space is devised in Refs. [16,22]. A method based on relative Lyapunov function is proposed in Ref. [15], which could potentially handle the consensus problems of systems with nonlinear or even heterogeneous agents.

The theories about dynamic multi-agent systems have been highly developed in systems science. However, the application instances associated with these theories that can well support them are seriously absent. Our attempt introduces a scenario from economics, in order to apply, verify, and enrich the relevant theories in systems science.

As far as our knowledge is concerned, nearly all the existing discussions seek an achievement of consensus, without considering any non-consensus situation; whereas our research endeavors oppositely to turn the viewpoints to the anti-consensus cases by revealing that sometimes consensus maybe detrimental.

The distinction between the current work and that in Ref. [8] is evident in four aspects. (1) The kernel of current model is a typical dynamic multi-agent system described by state space equation. (2) There exist nonlinearities in the migratory mechanism of Ref. [8], whereas the dynamic equation in the current model keeps being linear, conforming to the typical state space framework to describe dynamic systems. This would be convenient to pursue the principles of migration analytically, with the potential utilization of the abundant theories from systems science. For instance, a precise condition for consensus can be derived according to the present model. (3) The migratory process in Ref. [8] is iterative, whereas the variables in the current model, such as the time and the propensity to migrate, are continuous. (4) The current model takes the influence of the topology of communication network into account.

The organization of the main body of this paper is as follows. Section 2 briefly introduces the basic economic setting as background knowledge. Section 3 describes the dynamic migration mechanism in detail. Section 4 discusses the relevant consensus problem, analytically. Section 5 contains several simulation instances to illustrate the model. Finally, Section 6 concludes the paper.

2. Economic setting

The economy of a society is supposed to comprise two sectors: urban and rural. The urban sector is formed by firms engaged in manufacturing business, whilst the rural sector is formed by farms engaged in agriculture. Such a dual structure is typically adopted by the economic literature addressing the rural–urban migration phenomena [1,2,8,24,25].

The basic economic setting of both sectors in the current paper is inherited from Ref. [8]. The primary conclusions are quoted as follow. The readers can refer to Ref. [8] for detailed analysis.

Let N_u denote the population of urban sector. The average wage in the manufacturing sector is a function of N_u

$$w_m = \xi_2 N_u^{\alpha-1} \tag{1}$$

where $0 < \alpha < 1$ and ξ_2 is a constant calculated as

$$\xi_2 = \alpha A_m \left(\frac{\eta}{1-\eta}\right)^{\alpha\eta} \left[\left(1-\frac{\eta}{\mu}\right)\frac{1}{Z_m}\right]^{\alpha-1}$$

with the parametric constants $A_m > 0$, $0 < \eta < 1$, $\mu > 0$, and Z_m denoting the quantity of firms.

In the rural sector, the average income per worker is also a function of the rural population

$$w_a = \xi_4 p(N - N_u)^{\phi-1} \tag{2}$$

where $0 < \phi < 1$; N denotes the population of entire society; and ξ_4 is a constant calculated as

$$\xi_4 = A_a \phi / Z_a^{\phi-1}$$

with the parametric constants $A_a > 0$ and Z_a denoting the quantity of farms.