Modelling Complexity of Economic System with Multi-Agent Systems

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Abstract: Agent-based computational economics (ACE) is a multidisciplinary area using the agent-based approach for deeper understanding of economic phenomena occurring in the micro or macro-level. This paper investigates the application of multi-agent systems for modelling and simulation of virtual economy for research of self-organizing principles and adaptability of economic subjects. The proposed agent-based model uses four basic types of autonomous agents. Each one is responsible for crucial activity (consuming, production, mining, transporting) ensuring existence of the modelled virtual economy. Presented model is simplified in several aspects, for example banking operations or activities of government are not included in the model, but the model provides useful basis for the research of economic processes and progress of the city of Hradec Králové.

1 INTRODUCTION

Complex systems dispose a lot of highly interconnected components able to influence each other on the basis of its state or state of the environment. Interactions between these components can lead to the occurrence of emergent properties which are not a part of these individual units. Complexity is investigated with the aid of different modelling approaches (Kotzian et al., 2011). Multi-agent systems are stochastic and decentralized systems which are used as a bottom-up modelling paradigm for better understanding of these complex systems. This approach can be applied in the study of economic subjects' behaviour (consumers, households, companies, congregations or countries) that can exhibit complex behaviour (Tučník, 2010), (Čech and Bureš, 2009). Agent-based Computational Economics (ACE) uses computational tools in the study of microeconomic or macroeconomic processes for deeper understanding and effective influencing of the economic systems. ACE is defined according to (Tesfatsion, 2006) as: *"The computational study of economic processes modeled as dynamic systems of interacting agents."* Agent-based paradigm is a natural approach for study of economic processes, because it is able to model and simulate a large number of interacting entities and study adaptive or self-organized systems with the emergence. The economy can be perceived as complex adaptive and evolving system (Tesfatsion, 1999); (Bruun, 2006).

This paper investigates the application of multi-agent systems for research self-organizing principles and adaptability in virtual economy. The proposed model of virtual economy is intended to be modular and its complex behaviour should emerge through mutual interactions of a large number of agents. These agents use standard economic behaviour to pursue their goals, such as maximizing profit or utility, and are able to self-organize into structures allowing processing of resources in the given environment and creating production and supply chains with maximum efficiency as much as possible. Although the proposed system is in several aspects simplified – banking sector and government are not included in the model – the presented model provides useful basis for the research of adaptation and self-organisation mechanisms of virtual economy.

The paper is structured as follows: the section 2 mentions related applications of agent-based approach in the study of economic systems, the section 3 describes the proposed conceptual model of virtual economy, the section 4 introduces the initial computational model of virtual economy, the section 5 mentions future research activities and the section 6 concludes the paper.

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2 APPLICATIONS OF AGENTS IN ECONOMICS

The agent-based modelling and simulations are applied for solving different problems related to the economy or management. For instance, Kasbah platform is developed at the MIT Media Lab for automation of business processes, e. g. selling, buying and negotiation are realized only by autonomous agents. The user specifies the initial parameters for agents (description of trading product, prices of products or acceptable price of products) (Chavez and Maes, 1996). Project MAGMA proposes the prototype of virtual market in which buying, selling, usage of bank services and advertising are taken into account (Tsvetovatyy et al., 1997). Agents are used also in the VEMMA model – the virtual electronic marketplace using mobile agents which are able to negotiate about products prices. Decision-making of autonomous agents is based on their preferences and local parameters (Aklouf and Drias, 2006). An agent-based architecture for e-business is introduced in (Jain et al., 2011) where agents sell and buy selected kinds of fruits. The multi-agent approach can be used also in modelling adaptive behaviour of firms which compete with each other on the shared market (Guessoum et al., 2004). Economic multi-agent system is used in (Vidal and Durfee, 1998) to determine when agent should behave strategically (i.e. learn and use models of other agents), and when it should act as a simple price-taker. Their results show how savvy buyers can avoid being cheated by sellers, how price volatility can be used to quantitatively predict the benefits of deeper models, and how specific types of agent populations influence system behaviour. Damaceanu and Capraru (2012) focus their attention on banking market. In their study, they conduct 11 computer experiments and study the evolution of various banking market indicators such as total amount of money, savings, wallets, or bank reserves. Due to its complexity, Sinha et al., (2011) studied and created model of petroleum supply chain. Dosi et al., (2008) develop an evolutionary model of output and investment dynamics yielding endogenous business cycles. The model describes an economy composed of firms and consumers. Whereas firms belong to two industries, consumers sell their labour and consume their income. Simulation results show that the model is able to deliver self-sustaining patterns of growth characterized by the presence of endogenous business cycles.

3 CONCEPTUAL MODEL

Conceptual model of virtual economy is proposed in this paper. The model represents the production and consumption processes in real economies. The general aim is to study adaptive and self-organized principles which are behind the real economy. Economic principles of effective price and quantity settings under specific demand and capacity constraints (Pennings, 2001) are modelled and simulated with the aid of multi-agent systems. The focus is on trading products, services and offering work on a labour market. Virtual economy simulation is similar to the work of Deguchi, et al., (2001), however, in that representation the considered entities are more specific producing more complicated net of relations than necessary. Trust issues as discussed for example in (Gazda et al., 2012) and similar concerns are not of primary attention in our virtual economy. The presented model of virtual economy consists of four types of autonomous agents:

- Consumer (C-agent);
- Factory (F-agent);
- Mining (M-agent);
- Transport (T-agent).

Banking and government sector are not included in the model because of the simplicity and clarity of relations. The basic architecture of the virtual economy model is depicted in the Figure 1.

Consumer agents are economic entities consuming products and services (i. e. goods) and offer work. They are able to buy goods based on their wealth. The wealth of this agent is a product of work and qualification (the higher qualification the faster accumulation of wealth). A consumer agent makes a trade-off between investment into higher qualification (e_c) and consumption. The consumption function embodies the combination of consumed products and the speed of consumption. The combination of products forms a pattern of consumption that can be used to divide consumers into three categories: low income, middle income and high income consumers. The pattern determines the ratio of goods that the consumer agent is buying. Three types of goods are considered in our model: necessity, normal and luxurious goods.

Factory agent (a company) is responsible for transforming input to output (i. e. material and other products to final product that is bought by consumer agent or sub-product that is used by another factory agent). The consumption function determines materials and their proportions. The production

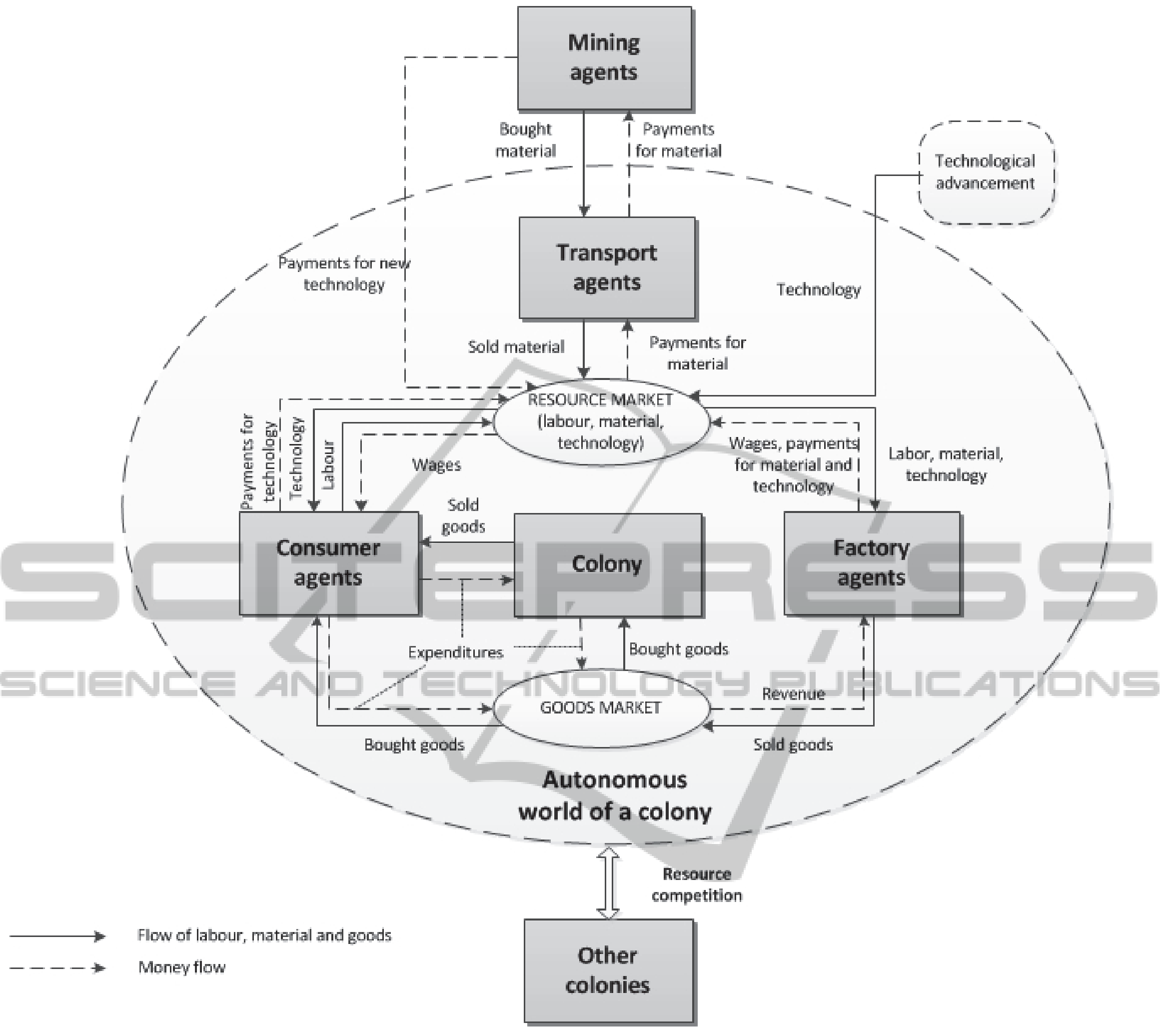

Figure 1: Conceptual model of proposed virtual economy.

function determines the portfolio of goods produced. Production requires workforce i.e. employing consumer agents. The production depends on the technological level e_f and qualification of the workforce i.e. employed consumer agents e_c. The production equation is as follows:

$$\sum_{i=1}^{n} k_i^{con} x_i + WF \xRightarrow{production} e_C e_F \left(\sum_{j=1}^{m} k_j^{pro} y_j \right) \qquad (1)$$

Let k_i^{con} be the speed of consumption of a material xi and WF is the workforce; e_c is qualification level of a consumer agent and e_f technological level factory agent; k_j^{pro} to be the speed of production of a product y_j.

Mining agent is responsible for transforming resources into raw material that is used by factory agents for production of products or services. The cost of mining is determined by the consumption function in which the energy and technology necessary for mining is reflected. Each mining agent supplies only one type of raw material. Raw material, as transformed from resources, is stocked in order to be later sold to transport agents.

Transport agents are intermediaries between mining agents and factory agents. The cost of transportation is given by the distance. The task of transportation agent is to find the most economical route in case of barriers on the road. The performance of a transportation agent is determined by the speed of mobility, capacity and technology. Transport agent does not have any wealth and buys material on behalf of a factory agent. The technological advancement of a transportation agent is also the same as for the factory agent. Transportation agent is always buying all available material up to the capacity of transportation. Transported material that is not used directly in production is stored in factory agent warehouse.

The proposed model of virtual economy contains also the representation of a society of agents which is called “colony” in this context. The colony is a compact formation of consumer, factory and transportation agents. Mine agents are not a part of the colony. They are distributed in the environment, depending on the resources they process. The colony has the two basic characteristics: position in environment and the size of population. Colonies compete for resources that are supposed to be scarce.

The success of a colony can be measured by wealth. The wealth of a colony is given by the sum of wealth of all agents. Due to different colony populations the comparison among colonies requires computing wealth per agent. The formula is as follows:

$$cw_{COL} = \frac{\sum_{i=1}^{n}\left(w_{C,i} + w_{F,i}\right) + w_{COL}}{p} \qquad (2)$$

where

$$p = \sum_{i=1}^{n} c_{COL,i} \qquad (3)$$

4 COMPUTATIONAL MODEL

Initial model of the virtual economy is developed in the java-based NetLogo modelling platform that is suitable for modelling complex systems (Brabenec and Tučník, 2012), see Figure 2. The following processes are simulated in the NetLogo:

- Raw material extraction by M-agents;
- Receiving raw material by T-agents from M-agents;
- Transportation of raw material by T-agents into the colony;
- Detection of obstacles during the transportation (swamp, forest, water reservoir, sand);
- Production of products by F-agents;
- Consuming of products by C-agents;
- Buying/selling products by C-agents (the lowest price is accepted).

The user can set up mainly the number of colonies (1 – 4), size of each of the colony (1 - 100 C-agents), position of colony, number of M-agents (0 – 5), terrain (type of obstacle), number (type) of sources, production chains, number of outputs produced by F-agents. FIPA ACL extension developed by Ilias Sakellariou (Sakellariou, 2008) is used for modelling communication between agents, because the pure NetLogo tool supports only reactive agents without specific communication language.

Elementary coordination principles, competitive behaviour during the sources management, distribution of sources, living standard or level of background can be investigated with this multi-agent-based model. Couple of disadvantages of the NetLogo were discovered during the model development. More complex behaviour patterns are hardly implemented and long-term planning cannot be adequately included. GUI can be chaotic in case of a lot of control or monitoring elements (monitors, buttons, input/output fields, graphs, sliders, switches). Hence, the different multi-agent environment is going to be selected for modelling more complex behaviour of virtual economy. Multi-method simulation software AnyLogic is considered for this purpose.

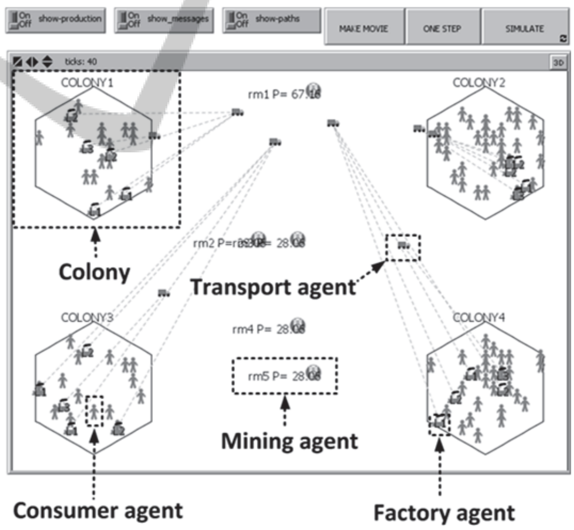

Figure 2: Initial model of virtual economy in NetLogo.

5 FUTURE RESEARCH

Proposed model of virtual economy is simplified. Capital market, labour market or governmental sector is not a part of our initial model. Future research is focused on the development of more complex model with different strategies of agents and research of effectiveness of agent´s communities in different settings. Our aim is to investigate self-organizing capabilities of the system using models of behaviour from economic theory with the application of the multi-agent approach. The final model should correspond with the behaviour of the economic subjects existing in the city of Hradec Králové and contribute to development of the "smart city" concept (Mikulecký, 2011). On the basis of the realized state of the art, no other study aimed at the modelling the economy of the city of Hradec Králové was not found. The intended system must have the following attributes:

- Stability: the system should be able to maintain itself for as long as possible, ideally for unlimited time;
- Efficiency: the system should be able to optimize resource allocation considering production capabilities and provide capacity for suitable distribution of products;
- Adaptation and dynamism: the system should be able to be flexible due to changing conditions of the environment (i. e. resources reallocation or reorganization its structure).

Real data are crucial part in multi-agent modelling and simulation. It is necessary to have model that is reflective of reality as much as possible. Actual NetLogo model is not based on the real data. Real data are going to be used in the next model. Database of the Czech Statistical Office (CSO, 2013), e. g. data related to the city of Hradec Králové, is the main source of real data. A lot of datasheets are freely available.

The economical context in which proposed system operates is used to maximize the operational potential of the whole multi-agent system. Economic notions like "customer satisfaction" or "maximization of profit" are excellent to define target parameters for performance of individual entities in the system. The autonomous entities (agents) may then adopt different strategies in order to achieve appropriate level of efficiency in their actions. It is our intent to achieve desired behaviour of the whole system by behavioural patterns that will emerge by interaction of large amount of small individual agents with each other. The work is divided into two phases. Case of single multi-agent community (colony) is investigated in the first phase. Activities in the first phase are focused on the efficiency and productiveness of the colony and its self-organizing capabilities. The second phase is focused on multiple colonies interacting with each other within the given environment. There will be several (or all) resources in the environment present in a limited amount only. Individual colonies have to negotiate distribution (or ownership) in this case. It is assumed that colonies would be encouraged to specialize in their production, according to given allocation of resources in the environment. This will lead to increase of mutual dependency of colonies on each other and emphasise the need for their efficient cooperation. Application of scenarios focused on maximizing performance of colonies against each other is planned in the final phase of the project.

6 CONCLUSIONS

Actual state of the art shows that there is a strong tendency for formal defining of organizational structures and policies in self-organizing systems. Multi-agent systems are natural alternative for modelling complex systems occurring also in the economic theory.

The initial model of virtual economy is developed in the NetLogo, but the intended model have to more sophisticated, modular, adaptive and based on the real data. Consisting of individual agents of transparent architecture, the complex behaviour emerges over time as a result of their mutual interactions. By defining consumption patterns for consumer agents, system output could be modified to produce selected type of goods or services. This will allow us to study and investigate wide range of scenarios under changing conditions.

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