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Abstract

The tremendous development of an easy access to computational power within the last 30 years has led to the widespread use of numerical approaches in almost all scientific disciplines. The first generation of simulation models was rather focused on stylized empirical phenomena. With agent-based modelling, however, the trade-off between simplicity in modelling and taking into account the complexity of the socio-economic reality has been enhanced to a large extent. This paper serves as a basic instruction on how to model qualitative change using an agent-based modelling procedure. The necessity to focus on qualitative change is discussed, agent-based modelling is explained and finally an example is given to show the basic simplicity in modelling.

Keywords: agent-based modelling, methodology, evolutionary economics, qualitative change.

JEL-Classification: B52, O30.

1. Introduction

The tremendous development of an easy access to computational power within the last 30 years has led to the widespread use of numerical approaches in almost all scientific disciplines. Nevertheless, while the engineering sciences focused on the applied use of

simulation techniques from the very beginning, in the social sciences most of the early examples of numerical approaches were purely theoretical.

There are two reasons for this. First, since the middle of the 20th century, starting with economics, equilibrium-oriented analytical techniques flourished and were developed to a highly sophisticated level. This led to the widely shared view that within the elegant and formal framework of linear analysis offered by neoclassical economics, the social sciences could reach a level of accuracy not previously thought to be possible.

Second, within the same period, new phenomena of structural change exerted a strong influence on the social and economic realms. Despite the mainstream neoclassical successes in shifting the social sciences to a more mathematical foundation, an increasing dissatisfaction with this approach emerged. For example, by the 1970s the benchmark of atomistic competition in neoclassical economics had already been replaced by the idea of monopolistic and oligopolistic structures under the heading of workable competition (e.g. Scherer/Ross (1990)). A similar development emphasising positive feedback effects and increasing returns to scale caused by innovation led to the attribute "new" in macroeconomic growth theory in the 1980s (Romer (1990)).

In addition to these stepwise renewals of mainstream methodology, an increasingly larger group claimed that the general toolbox of economic theory, emphasising rational behaviour and equilibrium, is no longer suitable for the analysis of complex social and economic changes. In a speech at the International Conference on Complex Systems organised by the New England Complex Systems Institute in 2000, Kenneth Arrow stated that until the 1980s the "sea of truth" in economics lay in simplicity, whereas since then it has become recognised that "the sea of truth lies in complexity". Adequate tools have therefore to include the heterogeneous composition of agents (e.g. Saviotti (1996)), the possibility of multilevel feedback effects (e.g. Cantner/Pyka (1998)) and a realistic representation of dynamic processes in historical time (e.g. Arthur (1988)). These requirements are congruent with the possibilities offered by simulation approaches. It is not surprising that within economics the first numerical exercises were within evolutionary economics, where phenomena of qualitative change and development are at the front of the research programme.

The first generation simulation models were highly stylised and did not focus on empirical phenomena. Instead, they were designed to analyse the logic of dynamic economic and social processes, exploring the possibilities of complex systems behaviour. However, since the end

of the 1990s, more and more specific simulation models aiming at particular empirically observed phenomena have been developed focusing on the interaction of heterogeneous actors responsible for qualitative change and development processes. Modellers have had to wrestle with an unavoidable trade-off between the demands of a general theoretical approach and the descriptive accuracy required to model a particular phenomenon. A new class of simulation models has shown to be well adapted to this challenge, basically by shifting outwards this trade-off[1]: So-called agent-based models are increasingly used for the modelling of socio-economic developments.

This paper deals with the changed requirements for modelling caused by the necessity to focus on qualitative developments which is generally highlighted within evolutionary economics and the possibilities given by agent-based models. The next section is concerned with the importance of an analysis of qualitative development and it is shown that evolutionary economics is offering an adequate framework for this. Section 3 then focuses on agent-based-modelling as "the" tool that allows incorporating endogenously caused development processes. Section 4 gives an illustrative example of an agent-based-model. Section five summarizes the whole story.

2. Qualitative Change in an Evolutionary Economics Perspective

When concerned with the examination of change and development processes within industrialized economies economists usually focus on the movement of certain variables they consider a good description of the basic effects of economic growth and development. In mainstream economics the phenomenon of economic development is e.g. empirically analysed on the macro-economic level as the improvement of total factor productivity in time which lowers prices and leads to the growth of incomes. Accordingly, most often the GDP per capita is used as an indicator describing economic development in a quantitative fashion. Although it is impressing to observe the growth of income in economies over a long time span, this indicator, due to its quantitative nature only, does not give any idea about the structural and qualitative dimensions underlying economic development. This becomes even more obvious on the sectoral level where the analysis is most often restricted to long-run

[1] See e.g. Gilbert and Troitzsch (1999).

equilibrium structure describing e.g. the number of firms in a particular industry without putting emphasis on those factors driving the emergence and maturation of industries. By restricting their analysis on the quantitative dimension, the economic mainstream implicitly confines itself to the analysis of a system characterized by a constant set of activities basically neglecting innovation processes.[2]

However, in less orthodox economic approaches it is argued, and it is indeed also one of Schumpeter's major contributions, that economic development does also include prominently qualitative changes not only as an outcome but also as an essential ingredient which justifies us to speak of transformation processes going on. Qualitative change manifests itself basically via innovation of different categories (e.g. social, legal, organizational) of which technological innovation very likely is among the most important ones. Qualitative change is the transformation of an economic system, characterized by a set of components and interactions into another system, with different components and different interrelationships (e.g. Saviotti (1996)). An analysis of qualitative change therefore necessarily has to include the actors, their activities and objects which are responsible for the ongoing economic development. An example for the significance of qualitative changes can be found in figure 1 which displays the emergence of new industries in the internet sector in the 1990s for Germany. What strikes immediately is that anything but an equilibrated regular or proportional development is visible: Instead new firms appear in swarms, to use a notion coined by Schumpeter (1912) and sometimes almost no activities occur. Of course there are many other variables which do also reflect the importance of the qualitative dimensions of economic development e.g. on a macro-economic level the changing composition of the employment structure (*Fourastier Hypothesis*), on a meso-level the regional specialization patterns or on a micro-economic level the obsolescence of old and the emergence of new knowledge like the biotechnology revolution in pharmaceuticals, to name a few. By its very nature, the transformation of an economic system is a multi-facetted phenomenon. Accordingly, it is misleading to focus only on quantitative changes of the economy when analysing the driving factors of the transformation of economic systems over time. To better understand the mechanisms and dynamics behind the observed developments one has to explicitly include the qualitative dimensions. To achieve this, economic analysis has to

[2] Gunnar Eliasson and Bo Carlsson (2003): Economic growth can be described at the macro-economic level, but it can never be explained at that level. … economic growth results from the interaction of a variety of actors who create and use technology and demanding costumers.

consider – besides the prevailing cost-orientation – an important knowledge- and learning-orientation.

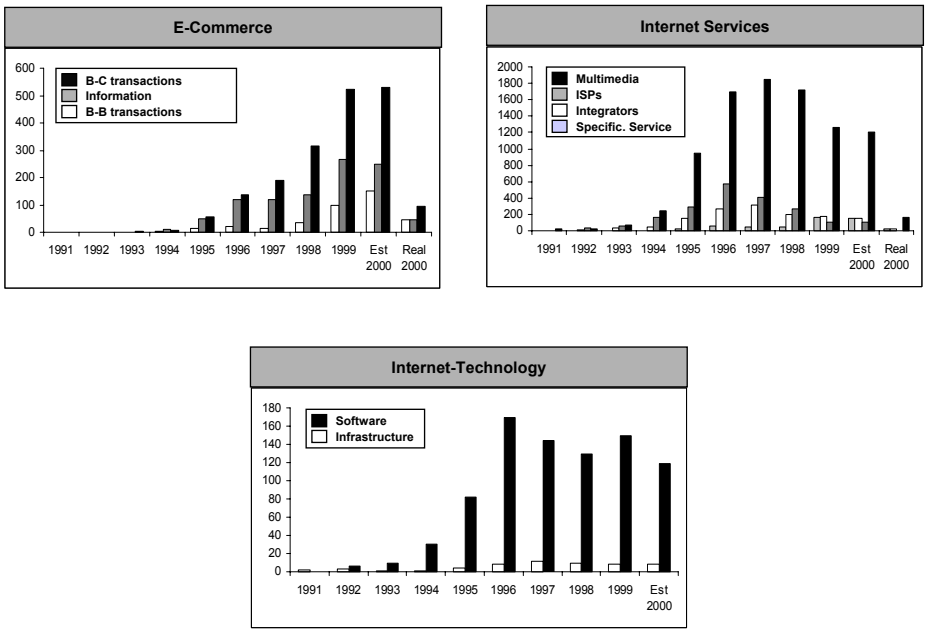

Figure 1: Swarms of new firms in the internet industries (Germany)
Source: e-startup.org database, survey of 332 venture capital firms, analyses of insolvency databases, Newsfeed and other public sources.

The following paragraphs are concerned with the implications of this knowledge-orientation, which can also be considered as the heart of the matter of evolutionary economics.

Knowledge-based approach of evolutionary economics

It is beyond the scope of this contribution to discuss in detail the criticism brought forth by evolutionary economics with respect to assumptions underlying the mainstream economic reasoning. A major discussion can be found among others, in Dopfer (2001), Clark and Juma (1987) and Silverberg (1988). For our purposes it is sufficient to mention three major points, evolutionary economists claim to be of outstanding importance in the discussion of economic development processes and which are incompatible with traditional economic approaches. These points are also constitutive for that strand of literature within evolutionary economics which is concerned with industry evolution and technological progress namely the Neo-

Schumpeterian approach. Here, instead of the resource- or incentive-orientation of neoclassical industrial economics a knowledge-orientation focuses on the investigation of industries and innovation processes in particular. First of all, the Neo-Schumpeterian theory wants to explain how innovations emerge and diffuse over time. A specific feature of these processes is uncertainty, which cannot be treated adequately by drawing on stochastically distributions referring to the concept of risk. Therefore, the assumption of perfect rationality, underlying traditional models cannot be maintained, instead the concepts of bounded and procedural rationality are invoked. Consequently, actors in Neo-Schumpeterian models are characterized by incomplete knowledge bases and capabilities. Closely connected, the second point concerns the important role heterogeneity and variety plays. Due to the assumption of perfect rationality, in traditional models homogeneous actors and technologies are analysed. Heterogeneity as a source of learning and novelty is by and large neglected, or treated as an only temporary deviation. Finally, the third point deals with the time dimension in which learning and the emergence of novelties take place. By their very nature, these processes are truly dynamic, meaning that they occur in historical time. The possibility of irreversibility, however, does not exist in the mainstream approaches, relying on linearity and equilibrium.

Thus, traditional economic theories, summarized under the heading of incentive-based approaches, with their focus on cost-based and rational decisions only, are excluding crucial aspects of actors' behaviours and interactions, which are influenced by a couple of factors lying by their very nature beyond the scope of these approaches. Although, of course, cost-benefit calculations (with respect to innovation itself a problematic activity) play an important role, the actors' behaviour is influenced additionally by several other factors as learning, individual and collective motivation, trust etc. It is the role of these factors the knowledge-based approach of evolutionary economics explicitly takes into account.

By switching from the incentive-based perspective to the knowledge-based perspective the Neo-Schumpeterian approaches have realized a decisive change in the analysis of the transformation of economic systems. In this light the introduction of novelties mutate from optimal cost-benefit considerations to collective experimental and problem solving processes (Eliasson (1988)). The knowledge-base of the actors is no longer perfect, instead a gap between the competences and difficulties which are to be mastered opens up (Heiner (1983)) (C-D gap). There are two reasons responsible for this C-D gap when it comes to innovation: on the one hand, technological uncertainty introduces errors and surprises. On the other hand, the very nature of knowledge avoids an unrestricted access. Knowledge in general, and new

technological know-how in particular, are no longer considered as freely available, but as local (technology specific), tacit (firm specific), and complex (based on a variety of technology and scientific fields). To understand and use the respective know-how, specific competences are necessary, which have to be built up in a cumulative process in the course of time. Following this, knowledge and the underlying learning processes are important sources for the observed heterogeneity among agents.

Challenges for analysing qualitative change

From the discussion above we can identify two major challenges for an analysis of qualitative change:

The first challenge is that a theoretical framework adequately displaying our notion of qualitative change has to incorporate concepts that comply with the notion of development of evolutionary economics in the sense Nelson (2001) discussed. Basically he refers to path-dependencies, dynamic returns and their interaction as constitutive ingredients for evolutionary processes in the socio-economic realm.

The second challenge is that we generally have to focus on both the micro- and meso-level of the economy as to our understanding the term qualitative change refers to a changing composition of components and interaction of and in the economic system. In doing so, we can identify some stylized facts that are considered of crucial importance when qualitative change in an economy is considered. The most obvious ones are:

First, an increasing importance of knowledge generation and diffusion activities is observed at least in those sectors of the economy that are considered to be the most dynamic and innovative ones. This coins the notion of a transformation of the economy into a knowledge-based economy. Second, this is accompanied by a continuously increasing specialisation and related to this an increasing variety of products and services coexisting simultaneously. Third, specialisation and differentiations goes hand in hand with an increasing importance of (market and non-market) interactions between the agents. Fourth, behind this increasing variety we observe innovation processes that at the same time improve efficiency of the production process and the quality of the products. Fifth, this innovation process is driven by competition selecting between different technological alternatives. Finally, the environmental constraints can be considered as filter- and focusing devices in this selection process either supporting or suppressing the diffusion of new technologies.

Once the relevance of these facts for the transformation of an economy is accepted the research has to account for those developments adequately.

Micro- and meso-perspective

Obviously this aim can only be accomplished by abandoning an aggregate perspective and instead focusing on a micro- or meso-level population approach (Metcalfe (2001)). This allows for examining diverse agents, their interaction and the knowledge induced transformation of both. By doing this, modelling openly has to take into account the importance of micro-macro-micro feedback effects (e.g. Silverberg (1988)). In their decisions actors obviously consider macro (-economic) constraints, but they also exert a significant influence on the altering of these constraints (Dopfer (2001)). The interrelated inspection of the meso- and the micro-level reflects the idea that analysis on the aggregated meso-level relies on description whereas the analysis of the micro-level focuses on explanation of the phenomena found on the meso-level (Dopfer 2001).

Knowledge

Considering this will lead to a revision of standard economic models as analysis here follows reality closely. Traditional 'production functions' include labour, capital, materials and energy. Knowledge and technology are only external influences on production. However, recent analytical approaches have been developed allowing the explicit consideration of knowledge as well as learning of actors as a means of acquiring new knowledge. Improvements in the knowledge base are likely not only to increase the productive capacity of other production factors, leading to the introduction of new products, as a visible outcome of the transformation process, but also to alter the organizational processes of knowledge creation, namely the interrelationships between the actors. Thus, transformation relates to a result- *and* a process-dimension similar to the terminology elaborated in Herrmann-Pillath (2001).

Consequently, it cannot be assumed that there exists a *fixed* set of activities and relationships in the social and economic sphere, especially when it comes to knowledge generation and learning. But this does by no means imply that no such set exists at all. It does exist, although, by its very nature it is evolving continuously. In this respect transformation does not only refer to the feedback processes, but it does also and with major relevance refer to the change

of the set itself during the process. This is evolution, and evolution is the very reason for not using static equilibrium theories or dynamic models to analyse qualitative developments as they are based on the notion of reversibility. The notion of evolution demands that we resort to ideas of irreversibility and path-dependence.

3. A Modelling Approach allowing for qualitative change: Agent-based modelling

An exploration of settings fulfilling the above requirements very likely needs numerical techniques, which are regarded as a major tool in evolutionary economics (Kwásnicki (1998), Aruka (2001)). Although simulation analysis comes in various flavours most of them reflect Boulding's call that we need to develop 'mathematics which is suitable to social systems, which the sort of 18th-century mathematics which we use is not' (Boulding (1991)). An increasingly growing literature today now is concerned with the application of so-called agent-based models. This approach consists of a decentralized collection of agents acting autonomously in various contexts. The massively parallel and local interactions can give rise to path dependencies, dynamic returns and their interaction. In such an environment global phenomena such as the development and diffusion of technologies, the emergence of networks, herd-behaviour etc. which cause the transformation of the observed system can be modelled adequately. This modelling approach focuses on depicting the agents, their relationships and the processes governing the transformation. Very broadly, the application of an *agent based modelling approach* offers two major advantages with respect to the knowledge- and learning-orientation:

The first advantage of agent based modelling is their capability to show how collective phenomena came about and how the interaction of the autonomous and heterogeneous agents leads to the genesis of these phenomena. Furthermore agent-based modelling aims at the isolation of critical behaviour in order to identify agents that more than others drive the collective result of the system. It also endeavours to single out points of time where the system exhibits qualitative rather than sheer quantitative change (Tesfatsion (2001)). In this light it becomes clear why agent-based modelling conforms with the principles of evolutionary economics (Lane (1993a), (1993b)). It is "the" modelling approach to be pursued in evolutionary settings.

The second advantage of agent-based modelling, which is complementary to the first one, is a more normative one. Agent-based models are not only used to get a deeper understanding of the inherent forces that drive a system and influence the characteristics of a system. Agent based modellers use their models as computational laboratories to explore various institutional arrangements, various potential paths of development so as to assist and guide e.g. firms, policy makers etc. in their particular decision context.

Agent-based modelling thus uses methods and insights from diverse disciplines such as evolutionary economics, cognitive science and computer science in its attempt to model the bottom-up emergence of phenomena and the top down influence of the collective phenomena on individual behaviour.

The recent developments in new techniques in particular the advent of powerful tools of computation such as evolutionary computation (for a summary of the use of evolutionary computation and genetic programming in particular see (Ebersberger (2002)) opens up the opportunity for economists to model economic systems on a more realistic i.e. more complex basis (Tesfatsion (2001)).

There is no entity, even though it may exist without the actors, which has no influence on the current state of the system or the development of the system. To illustrate this point, bits of information have nil influence on the system as long as they are not put into the appropriate context by a capable individual, influencing its activities. No resource can change the system as long as it is not used for carrying out certain activities that change the nature and the structure of the system. Hence in the centre of the stage there is the actor and its activities.

In the following sections a typical example for an agent-based model is introduced in order to highlight the specialties of this methodology. In particular the model deals with the emergence of new firms which are considered the outcome of entrepreneurial decisions of individual agents pooled together in networks. As the focus of this paper lies on the methodology of agent-based modelling we cannot go into detail with respect to the economic implications of the model but refer instead to Grebel, Pyka, Hanusch (2004) where all the economic concepts etc. used in the model are described in detail.

4. An illustrative example: An evolutionary economics model of entrepreneurial behaviour

(i) The general building blocks

A conceptual framework for the analysis of entrepreneurial behaviour can be composed of the following building blocks. In particular we consider *actors*, *action*, *endowments*, *interaction* and *evaluation & decision processes* as the decisive building blocks. The building blocks discussed here are not separate and unrelated entities. Rather are they the result of a systematisation process. They represent our conceptual view on the issue developed to clarify the analytical concepts and to facilitate implementation of the simulation model in the second step. In the following sections we sketch the building blocks.

Actors

We consider actors being the major driving force in the evolution. As such we regard them as the reason for the manifestation of qualitative developments going on in the system. They are the crucial components of the system. The model requires a multi-agent approach, which assumes that agents populating the model can be divided into various categories according to their initial endowments concerning the availability of capital, an entrepreneurial attitude as well as the respective technological competencies.

Accordingly, a central issue is the general design of the actors. Actors are represented as code that has the standard attributes of intelligent agents (Wooldridge and Jennings (1995)):

- autonomy, which means that agents operate without other agents having direct control of their actions and internal states. This is a necessary condition for implementing heterogeneity.

- social ability, i.e. agents are able to interact with other agents not only in terms of competition but also in terms of cooperation. This includes the possibility to model agents that show various forms of interaction blended from competition and cooperation.

- reactivity, agents are able to perceive their environment and respond to it.

- finally, proactivity enables the agents to take the initiative. This means that they are not only adapting to changing circumstances, rather are they engaged in goal-directed behaviour.

The above points indicate that the actors in the simulation are able not only to adapt their behaviour to a given set of circumstances but they are also in a Neo-Schumpeterian sense able to learn from their own experience and to modify their behaviour creatively so as to change the circumstances themselves.

When modelling the features and characteristics of the artificial agents the above mentioned standard attributes have to be implemented. As the agents in our conceptual framework can be characterized by their *actions*, *endowments*, *interactions* and their *evaluation & decision processes*, these conceptual building blocks have to be designed such as to reflect these attributes.

Actions

The different actions performed by the actors enable us to classify certain groups of actors. Not only is it the actions that we use as a demarcation of different groups of actors - their endowment might be another criterion for differentiation - but actions is one of the most striking one and connected to the other features such as endowments, etc. that will be discussed below. Basically we distinguish between individual agents and firms as networks of agents.

Routines

The actors are not modelled by a representative agent but by a population of heterogeneous agents. For any of our two subpopulations (agents and firms) rules and routines can be derived which govern the particular actions of the agents, the interaction and the interrelation of the agents within and among the sub-populations. Actions and routines are conceptually closely related and the latter can be considered as realizations of actions.

Hence it is routines through which the actors manipulate reality. It is not only the endowment with resources that shapes the nature of the actors, it is their individual routines that make up a large part of the actors heterogeneity. Nelson and Winter (1982) relate routines to the satisficing behaviour and the bounded rationality of actors. Routinized behaviour causes some stickiness and some inertia of the system that results in some stability of the system – stability, at least to a certain degree.

As indicated the actors manipulate reality through their routines. Hence routines are not only focused on internal procedures of the actors, but they also govern external relationships with actors of the same basic group and with actors of other groups.

Endowments

Access to material and immaterial resources, their availability together with the individual experiences make up the endowment of the actors. They combine the different components in order to realize their goals. Accordingly, the endowments are the crucial assets of agents in accomplishing their tasks.

All actors are characterized by different sets of endowments. Concerning the standard attributes of agents it is obvious that autonomy of the agents can only be achieved with the notion of personal and individual endowment of certain factors. It is the idea of individual property rights on production factors or income that enables us to model actors acting on with their sets of endowments.

Interactions

Concerning the relevant interaction between the different actors in our model, we have to consider a rather broad set of relationships ranging from competitive to cooperative, from bilateral to multilateral as well as from decentralized to hierarchical relations. Furthermore, a technological as well as an economic realm has to be considered.

Evaluation and decision processes

The discussion up to this point reveals that we have to cope with a heterogeneous set of actors. Some actors join networks with other actors and found a firm, other disentangle their networks or even go bankrupt with their previously founded firm. The question here is, how to unify the decision process of such a diverse set of actors while preserving the possibility for heterogeneity. After having introduced the basic conceptual building blocks in a rather abstract and general way the following sections deal with the actual model of entrepreneurial behaviour.

(ii) Modelling entrepreneurial behaviour

The starting point of the model is the micro-level. The driving force of an agent-based model is the agent. While an incentive-based model would rather focus on facts and phenomena,

external to the actor, a knowledge-based view has to thoroughly investigate the agent. This also raises methodological issues. In principal, the former – that is orthodox methodology – uses the Newtonian mechanics which requires the concept of a *homo oeconomicus* as a necessary condition. The *homo oeconomicus* performs a robustly optimal behaviour. In case behaviour is deterministic, the usage of analytical tools (equilibrium analysis) becomes legitimate. In return, this methodology makes it difficult to discuss psychological and sociological aspects of agents. The *homo oeconomicus* has been deprived from any psychological and sociological qualities that indeed affect individual (economic) behaviour. As much as orthodox methodology asks for such a perfectly rational and therefore homogeneous agent within a supposedly deterministic world, the need to shed some light on the non-deterministic aspects – the heterogeneity in agents' behaviour – asks for an adequate methodology. Agent-based modelling allows us to cope with the complexity emerging from the behaviour of heterogeneous actors.

In the following, a sketch of an agent-based model of entrepreneurial behaviour will be drawn.

Actors

Actors are boundedly rational. Their current individual state is the result of an ongoing path-dependent, cumulative and irreversible process. Their knowledge, their capabilities and their resources are the result of a congenitally determined learning and decision-making process. On these grounds, actors will make future decisions.

When we exemplarily investigate the emergence of entrepreneurial behaviour, a stereotypic agent may look as follows: the decision to become an entrepreneur might be driven by entrepreneurial traits (Schumpeter (1912), McClelland (1961)), by its knowledge and capabilities acquired by education and work experience (Hunsdiek and May-Strobl (1986), Goebel (1990)) and last not least, sufficient financial resources (Schumpeter (1939), Evans/Jovanovic (1989)). For simplicity, these three components, we call the entrepreneurial (ec), the capability (cc) and the financial (fc) component of our basic, bounded rational actor as shown in figure 2.

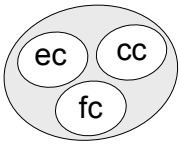

Figure 2: An actor and its endowment

Using a Schumpeterian concept of the entrepreneur, innovative behaviour will be dependent on the actor's capacity to make use of a new technology. Besides the fact that the actor's cognitive capacity might prevent him/her from innovating on a new technology in the first place, the possibility of not receiving the knowledge about the new technology may never make an actor an entrepreneur either, though having the potentials. As a result, the diffusion of knowledge is constrained by individual factors as well as the fashion of social interaction, which is the means to pass on such knowledge. This knowledge diffusion process can be easily modelled with a cellular automaton using percolation theory (Grebel (2004)).

For simplicity let us now consider only those agents who have received and understood the application of a new technology, then, it is more probable that these agents might undertake entrepreneurial actions, although not a necessarily.

Social interaction

An entrepreneurial decision cannot be considered in isolation. The context of a social group plays an important role in an actor's decision-making process: either supporting or disapproving a decision such as starting a new business. Some actors might be interested in a new technology (e.g. the internet) and begin proactively to gather new information and knowledge about it. Thus, a dynamic social interaction process keeps the agents forming new networks and thus building and restructuring connections as depicted in figure 3.

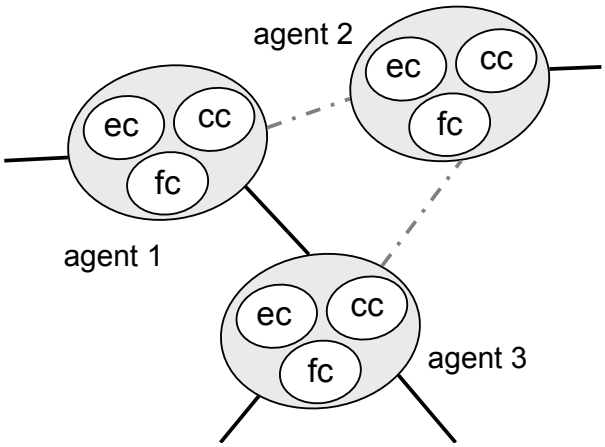

Figure 3: Actors forming a network

This social networking dynamic is an indeterministic, quasi-random process.[3] With a cellular automaton (Grebel (2004)) such quasi-random behaviour can be implemented into a model: placing the actors on a lattice, giving them certain rules when an where to move, a self-organizing process evolves that makes actors of a kind (having a comparable set of endowments) happen to bump into each other.

At any time an actor evaluates his/her chances to found a firm successfully, and so does he/her evaluate the chances of other network members to start a business and finally, they may decide to establish a firm altogether. See figure 4.

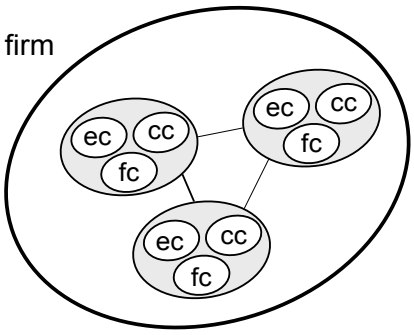

Figure 4: A firm founded by three actors

[3] Quasi-random means that such a search process is neither perfectly deterministic saying that the result of this process is always the optimal network, nor is the search process completely chaotic. Agents act goal-oriented but not perfectly rational.

So far the micro-level has been substantiated with the specificities of the actors, their endowments, their routines behaviour and their social interaction. At any point in time, each network constitutes a potential firm.

Micro-meso/macro feedback

Up to this point, the modelling procedure was strictly bottom-up. However, this is not the whole story. Though indeed entrepreneurial decisions are micro-level decisions with all the psychological and sociological aspects involved, the meso and macro level also have a major influence on such kind of decisions. The emergence of new industries (e.g. e-commerce, etc.) is an endogenous process. It is an ever-changing process principally driven by micro behaviour. Nevertheless, economic indicators such as the rate of entry and exit, market concentration and the stage of an industry's life cycle have a feedback effect from the meso/macro level onto the micro level. Hence, the agents create their common economic reality and at the same time are guided by the same economic reality.

As a consequence, economic data (entry, exit, etc.) have to be taken into account within the decision-making process of the agents. Whether an actual firm is actually established not only depends on individual factors, the self and the group evaluation process, but also it depends on the evaluation of economic opportunities of a new technology, i.e. meso and macro data.

The module (heterogeneous oligopoly)

In order to implement this endogenous change, we have to use a module that produces this data given the agents' actions. This module is a simple heterogeneous oligopoly module (Grebel (2004)), which produces the data required. Once firms are founded, they take part in market competition. Each firm faces an individual demand curve which depends on the firm's competitiveness relative to the remaining incumbent firms' competitiveness. Thereby, the competitiveness is determined by the firm's balance in endowments. For example, firms that have less in the capacity component have worse chances than others. Firms learn over time and improve their efficiency, i.e. there is a first-mover advantage. This way, the firm's competitiveness is an endogenous result of the quasi-random search process of the agents.

The founding threshold

The heterogeneous oligopoly only serves as a selection criterion to generate the necessary data which influences micro behaviour. The module is interchangeable. The continuously produced data is fed via the so-called *founding threshold* into the decision-making process of the agents. Thus, the focus on micro behaviour is guaranteed and the model is kept parsimonious and simple. See figure 5.

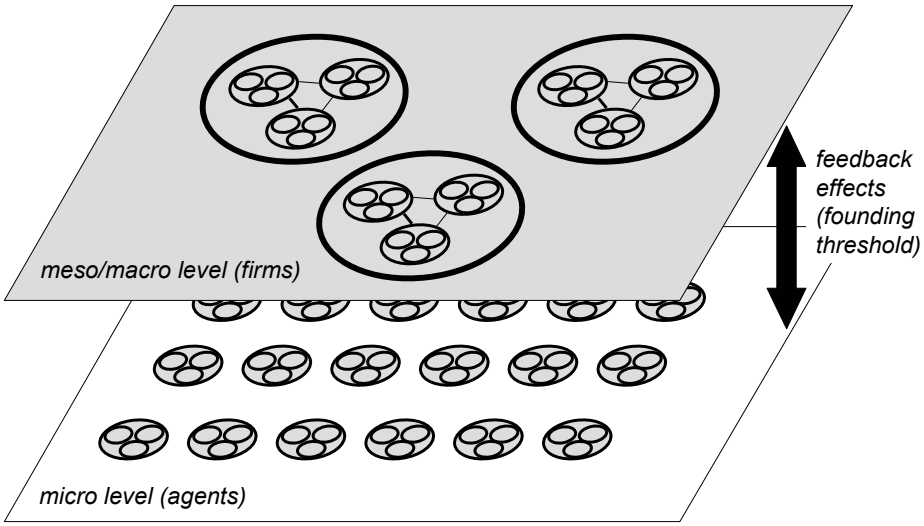

Figure 5: Micro-macro-feedback effects

Results

An agents-based model as it is developed in Grebel,Pyka,Hanusch (2004) has been conceptually outlaid above. The formal part can be found in the literature cited.

Now, with model as it was stated above various scenarios can be run. The endowments of actors can be fleshed out with empirical data or, as it was done in the simulation run shown below, can just be pseudo-random numbers. So it is done with the routine behaviour of agents. Certain, specified rules make them interact with each other. Hence, the start-up decision is an economic, irreversible decision, contingent to psychological and sociological aspects.

As figure 6 shows firms are founded by agents driven by the positive data generated by market competition. The founding threshold thereby depicts the ups and downs of the agents common attitude towards the economic development, which agents adapt their behaviour to.

Furthermore, we see the stylized facts of an industry life cycle (5 phases). That shows us that the underlying assumptions on agents' behaviour match the observed empirical data. Besides a good description of entrepreneurial behaviour from an economic as well as a psychological and sociological perspective, we obtain on top of it an explanation for seemingly random firm entries and, moreover, the selection process modelled separates competitive firms from non-competitive ones.

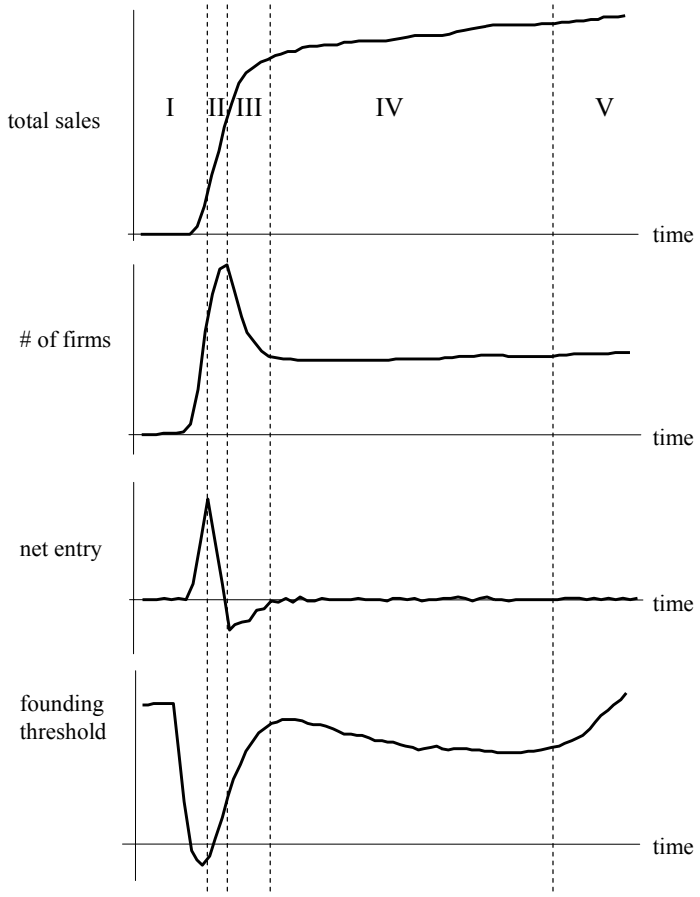

Figure 6: A selection of simulation results

Figure 7 serves to illustrate the heterogeneity among firms. Each firm founded has its individual competitiveness relative to others. Not all of the firms are successful and survive the early phase of competition. Some become insolvent and may exit the market, whereas others survive and grow. Furthermore, it has to be emphasized that the heterogeneity of firms

is no arbitrary assumption but the result of a decision-making process of bounded rational and therefore heterogeneous actors.

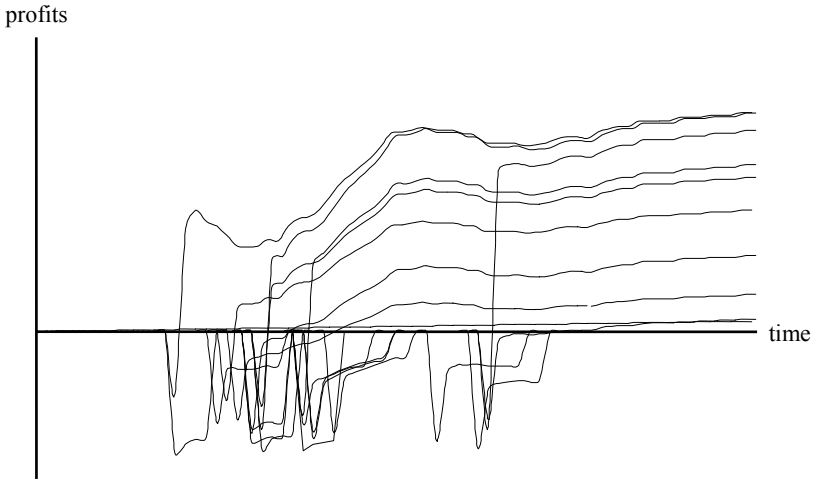

Figure 7: The performance of new firms

5. Conclusions

The paper deals with one of the most prominent challenges in social sciences today, namely the analysis of qualitative change. It is shown that evolutionary economics is offering an adequate framework for this, overcoming the severe restrictions orthodox economic approaches are confronted with. Emphasizing the role of learning, true uncertainty, heterogeneity of agents and irreversibility, within evolutionary economics qualitative development becomes an endogenous process driven by agents and their interactions.

Agent based models allow for an explicit consideration of these characteristic features and therefore can be considered as "the" modelling tool for the analysis of qualitative development and transformation processes. After having worked out the basic features and requirements of agent based models, their functioning is exemplarily shown by introducing an agent based model of entrepreneurial behaviour. This particular model is also demonstrating a second crucial advantage of this modelling technique: Agent based models are offering a platform for inter- and trans-disciplinary research. In the model of entrepreneurial behaviour for example several insights from psychology as well as the theory of social networks are embedded. In a way, agent based models can be considered a systemic approach, allowing the consideration and integration of different social "realities" which makes them an extremely

valuable tool for the analysis of social processes which generally can be considered as multifaceted phenomena.

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