An Agent-Based View of the Biotech Innovation System
Biotechnologické inovačné systémy z pohľadu teórie agentov

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Abstract

This paper develops an agent-based model of the biotechnology innovation system with the purpose to analyze the effects of public RTI (Research, Technology and Innovation) funding on innovative performance. Biotechnology is characterized as a research-intensive field where industrial and scientific agents operate in a highly dynamic environment. Interdependencies among agents are manifold, fostering dynamics and complexity in the system. While current agent-based models of the system have focused on the creation and exchange of knowledge among firms, this paper directs attention to public RTI funding and its impact on agent behavior in the system. The paper is methodological in nature, with the life sciences cluster of the Vienna region in mind that will be used as basis for empirical testing in a later stage of the project.

Key words: complexity, agent-based modeling, sectoral innovation systems, biotechnology.

Abstrakt

Táto práca rozvíja model systému biotechnolgickej inovácie s pohľadu agentov s cieľom analyzovať dôsledky verejného financovania výskumov, technológií a inovácií (RTI -Research, Technology and Innovation)), prostredníctvom inovačných metód. Biotechnológia je charakterizovaná ako silne orientovaná na výskum, kde priemyselné a vedecké orgány podnikajú vo vysoko dynamickom prostredí. Vzájomné vzťahy medzi agentmi sú rozmanité, vyvýja sa dynamika a komplexnosť v systéme. Zatiaľ čo súčasný systémový model orientovaný na agenta sa zameral na vytváranie a výmenu vedomostí medzi podnikmi, tento dokument smeruje pozornosť *na verejné financovanie výskumov, technológií a inovácií a ich vplyv na správanie agenta v systéme. Príspevok má metodologický charakter, ktorý má na pamäti „Life Sciences Cluster“ regiónu Viedne, že budú použité ako základ pre empirické testovanie v neskoršej fáze projektu.*

Kľúčové slová: *komplexnosť, modelovanie orientované na agenta, sektorové inovačné systémy, biotechnológia.*

Introduction

Biotechnology is a novel, research-intensive field that may be defined as "*the application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or nonliving materials for the production of knowledge, goods and services*" (OECD 2006, p. 7). Industrial and scientific agents in this field face a dynamic environment characterized by fast-expanding scientific knowledge and scattered expertise. The ability to create innovations is crucial for the competitiveness of firms, and high development costs are associated with long time lags in the commercialization of scientific results (Cooke 2002a). Thus, agents in this field tend to operate under high uncertainty, and, in order to keep pace with innovation trends, they engage in R&D networks (Powell et al. 2005). This cooperation in R&D creates relations and flows between the agents. Interdependencies foster dynamics and complexity in the biotechnical (abbreviated: biotech) innovation system.

We view biotechnology as a sectoral innovation system[1] which is characterized by interdependent agents and their non-linear interactions. A sectoral innovation system (Breschi and Malerba 1997; Malerba 2002) consists of a set of firms active in developing and making the sector's products and in generating and utilizing the sector's technologies. Processes of interaction and cooperation in technology development as well as processes of competition and selection in innovative and market activities form the relations within the system (Breschi and Malerba 1997, p. 131).

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See detailed information on innovation systems (Edquist 1997; Edquist and Johnson 1997), on regional innovation systems (Braczyk et al. 1998; Cooke et al. 1997) and on national innovation systems (Freeman 1987; Nelson 1993).

The objective of this paper is to suggest an agent-based model that allows for a considerable degree of heterogeneity among the agents and their interactions. Heterogeneity of both types appears to characterize the biotech innovation system. We take a systemic view on the system, and consequently identify the elements and agents of the system and their relations. This is due to the specific importance of systemic behavior and learning in this sector. The resulting performance of such a system can be more than the sum of its parts (Axelrod and Tesfatsion 2006, p. 1649).

The explosive growth in computer power over the past decades has shifted interest on agent-based computational models, computationally intensive methods for developing and exploring new kinds of economic models. Agent-based models allow the computational study of innovation processes modeled as dynamic systems of interacting agents who do not necessarily possess perfect rationality and full information. Whereas conventional models require a careful consideration of equilibrium properties, agent-based models stress innovation processes, interactions among economic agents, and out-of-equilibrium dynamics (Axelrod and Tesfatsion 2006, pp. 1649-1650; Fagiolo and Dawid 2008, pp. 351-352; Judd 2006, pp. 884-885; Pyka and Grebel 2006). Thus, agent-based models allow to enhance our knowledge not only about the processes of variety creation and selection, but also – and most importantly – about the co-evolution of the agents within the system (Malerba 2002, pp. 251-262).

In a later stage of the project the model will be empirically calibrated, using the life sciences cluster of the Vienna region as a reference. Agent-based models require detailed specifications of structural conditions, institutional arrangements, and behavioral dispositions (Tesfatsion 2006, pp. 843-865; Judd 2006, p. 885; Arthur 2006; Pyka and Fagiolo 2007). The life sciences cluster in Vienna (Life Science Austria Vienna Region 2007, p. 7), consisting mainly of red and green[2] biotech organizations, essentially goes back to a joint venture of Boehringer Ingelheim and Genentech in the mid-1980s (IMP 2009) that sparked off new dynamic activities, and has gained momentum since then. It is worth noting that the focus of Vienna's research policy is on biotechnology since 2003, and specific calls for research projects in this field are offered on a regular basis (Wiener Wissenschafts-, Forschungs- und Technologiefonds 2009).

The paper is organized as follows. The next section briefly describes the agent-

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[2] Red biotechnology is defined to involve research and application in medical and pharmaceutica science and includes the whole range from diagnostics to therapy. Green biotech covers agricultu ral and food biotechnology (OECD 2006, p. 88).

based modeling approach. Then we direct attention to the core agents in the system (industry agents, university agents, and research organization agents) characterized by specific knowledge endowments, while the section on *Interactions among Agents* focuses on the relations between these agents of various form, including interaction, and knowledge, labor and financial flows. The section termed *Measuring the Performance of the System* moves to the issue of how to measure the performance of the biotech innovation system. Subsequently, the role of public RTI funding in the system is discussed briefly. The paper closes with a short outlook.

The Biotech Innovation System

A system of innovation consists of a set of agents or entities such as firms and other organizations that interact in the generation, use, and diffusion of new – and economically useful – knowledge. The systems of innovation approach provides an important framework for understanding why some firms, sectors or regions are economically successful while others are not. The attractiveness of the systems approach stems from three features (Fischer et al. 2001, p. 15):

- *First*, it places innovation and knowledge creation at the very center of focus, and goes beyond a narrow view of innovation to emphasize its interactive and dynamic nature.
- *Second*, it represents a considerable advance over the network school of innovation (Håkansson 1987), due to the decisive shift in focus from firm to sector or territory, from the knowledge-creating firm to the knowledge-creating sector or territory.
- *Third*, it views innovation as a social process which is institutionally embedded, and hence lays special emphasis on the institutional context and the forms in which, and through which, the process of knowledge creation and dissemination occurs.

Three types of innovation analysis may be performed, depending on the context (Fischer et al. 2001, p. 15):

- the first refers to the micro-level of the system and attempts to analyze the internal capabilities of selected firms and the links surrounding them (knowledge relationships with other firms and with non-market organizations);
- the second refers to the meso-level of the system and focuses on specific subsystems and attempts to map knowledge and other interactions within and between subsystems;

- the third refers to the macro-level of the system and typically involves the use of macro-indicators, such as R&D personnel ratios, R&D expenditure intensity rates, patent intensity rates, and network indicators of various kinds which characterize the system in general terms.

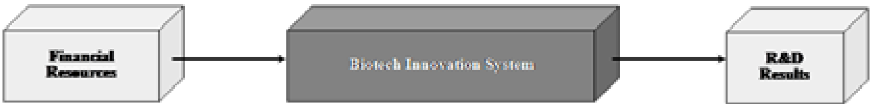

Figure 1: The biotech innovation system as a black box

From a macro-level perspective, the biotech innovation system is fed with financial resources as key input factor and R&D results of different kind as output of the system (Figure 1). The attraction of financial resources is an important concern of all agents in order to perform R&D projects (Gruber 2009). Organizations finance their projects either internally or externally, or as a mixture of both. Exclusively internal financing implies the reinvestment of profit made through the successful commercialization of innovative products. Apart from public RTI funding, venture and debt capital play an important role in financing R&D projects. Government funds build the focus of our simulation project and are divided into direct funding, initiated bottom-up (by the organization) or top-down (by the government), and indirect funding, institutional funding or the creation of competence centers. Indirect funding includes tax allowances or the deduction of R&D expenses from tax. The key performance aspects of the biotech innovation system are R&D results represented by scientific publications, patents, and the creation of high-tech jobs.

Agent-based modeling (ABM) is well suited for analyzing innovation systems exhibiting the following two properties: (a) the system consists of interacting agents, and (b) the system exhibits emergent properties, i.e., properties arising from the interactions of agents that cannot be deduced simply by aggregating the properties of these agents. When the interaction of agents is contingent on past experience, and when the agents continually adapt to that experience, mathematical analysis is characteristically rather limited in its ability to derive the dynamic consequences (Axelrod and Tesfatsion 2006).

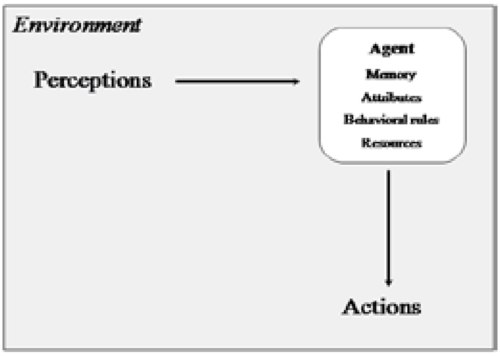

Figure 2: An agent embedded in its environment

The agents in our model are conceptualized as heterogeneous agents with respect to their perceptions, actions, and internal attributes (Billari et al. 2006, pp. 3-5). As indicated in Figure 2, an agent uses its knowledge to communicate (Genesereth and Ketchpel 1994, p. 48) and memorize information, and is viewed to act according to behavioral rules in order to reach a certain goal. An agent may refine its decisions in the course of time as it perceives its environment, responds to it, and learns from it. The agent is autonomous (Jennings 2000) and might operate alone, although, thanks to its social ability it interacts with others as well (Wooldridge and Jennings 1995, pp. 118-119). The internal state of an agent and its actions change the environment of the others. Beside the simulation of interactions between agents (Garcia 2005, p. 381), the integration of multi-level feedback effects is rendered possible (Kirman 1997).

By including different types of agents and their strategies, our model draws on previous research (Gilbert et al. 2007; Gilbert et al. 2001), in particular on the SKIN model (*Simulating knowledge dynamics in innovation networks*) developed by Gilbert et al. (2007) that focuses on market interaction and knowledge exchange among firms.

We depart from previous research in several aspects. First, we take explicitly public sector research, such as universities and public research organizations, and different types of public funding into account, and second, we focus on analyzing the effects of policy intervention in a localized biotech innovation system.

While the SKIN model represents a reductionist approach which according to the KISS (***K****eep* ***I****t* ***S****hort,* ***S****tupid*) belief is designed as simple as possible (Axelrod 1997), our model attempts to provide a more realistic view based on the principle of KIDS

(Hassan et al. 2008). This principle (***K**eep **I**t **D**escriptive, **S**tupid*) relates to models which emphasize the examination of factors and dynamic processes characteristic for the evolution of industries. By relying on work by Malerba and Orsenigo (2002, p. 667), we suggest a case-based model of the Vienna biotech innovation system which is sufficiently detailed in terms of time and space. Knowledge-related processes and political interventions regarding knowledge production and exchange are at the centre of the model.

The Agents: Assumptions and Behavioral Dispositions

The agent-based model distinguishes three types of core agents: university agents, research organization agents, and industry agents. While the university agents include not only universities but also universities of applied sciences (*Fachhochschulen*), research organization agents involve public or private non-profit research organizations. Industry agents include large diversified pharmaceutical firms (LDFs), multinational companies, and smaller dedicated biotech firms (DBFs) (Pyka et al. 2002, p. 79), but also start-up and spin-off companies. This variety is modeled by different attribute values for the particular agent type. Further agents considered are financial organizations such as banks that allow credits or venture capitalists which organize private capital for the agents' investments. Note moreover that governmental authorities, or public innovation policy agencies are important determinants of innovation in any innovation system (Edquist 1997, p. 2 and Edquist 2001, pp. 3-5).

Behavioral dispositions are characterized by specific knowledge endowments and other attribute values that govern the exchange processes among agents. We describe each agent by a set of kenes (see Table 1) representing its knowledge endowment (Gilbert 1997, pp. 8-10). A kene is a triple of variables incorporating capabilities (Cs), core competencies (CCs), and a particular expertise (E) level. An agent is assumed to be able to modify or expand its kene set through own R&D efforts or cooperation with other agents during joint R&D activities. No matter whether carried out alone or in collaboration, R&D is costly on the one hand, but, on the other hand it leads to the acquisition of new capabilities and core competencies for the agent's kenes.

Table 1: Kene structure

Kene element	Code	Scale type	Value
Capability	C	Categorical	1, …, 36
Core competency	CC	Categorical	1, …, 7
Expertise	E	Ordinal	1, …, 10

Note that the capabilities (Cs) of an agent may relate to a scientific or technological field, or a business domain (see Table 2), while the core competencies (CCs) relate to specific competencies within the particular C as outlined in Table 3. In contrast to Pyka et al. (2002), we define capabilities in terms of categorical rather than metric variables. As a concept of proximity on the set of capabilities, we employ the number of co-occurrences of two capabilities (activity domains) in the agent population, and use the respective Jaccard-Index (Leydesdorff 2008) as a measure of thematic proximity of these capabilities.

Table 2: Specification of the agent's capabilities

C	Capability in a scientific, technological or business domain
1	Analytical methods & services
2	Antibodies
3	Bacterial & viral diseases / Antiinfectives
4	Cardiovascular diseases
5	Cell & tissue culture
6	Clinical research & tests
7	Consulting
8	Dermatology
9	Diagnostics / Diagnostic technologies
10	Drug development / Drug delivery
11	Environmental issues
12	Enzymology / Protein engineering / Fermentation
13	Gene & cell therapy, viral vectors
14	Genomics
15	Immunology / Allergology
16	Industrial processing
17	Informatics in the life sciences
18	Lab equipment, medical & surgical equipment
19	Metabolomics
20	Medical technology & devices
21	Microbiology

22	Nanobiotechnology
23	Neurobiology / Neurodegenerative diseases
24	Nutrition / Food / Feed
25	Oncology
26	Pharmaceuticals
27	Plant breeding & genetics
28	Proteomics
29	Process technology
30	Regenerative medicine
31	Services (synthesis, sequencing, spectroscopy)
32	Stemcells
33	Structural biology
34	Vaccines
35	Veterinary activities
36	Others

Note: C denotes capability; the measurement scale ranges from 1 to 36. Source: Austrian Life Sciences Directory (2009).

Apart from their capability in scientific, technological, and business domains, agents are characterized by core competencies (CCs), as displayed in Table 3. Both, capabilities and core competencies are measured in terms of nominal variables. Every agent reaches a certain expertise level within each of its capabilities (C) which indicates the acquired know-how in the particular technological capacity over the time steps in the course of the simulation (Pyka et al. 2002, p. 173).

Table 3: Specification of the agents' core competencies

CC	Core competency within a particular capability (C)
1	R&D
2	Contract research
3	Production & processing
4	Sales
5	Service
6	Education & training
7	Others

Note: CC denotes core competency; the measurement scale ranges from 1 to 7. Source: Austrian Life Sciences Directory (2009).

Finally, agents are not only characterized by this knowledge endowments, but also by other attributes as entitled in Table 4 that are widely viewed to be crucial for agent behavior. Examples include the financial structure of the agent, its R&D infrastructure, absorptive capacity[3], cooperation behavior, search strategy for partners, an agent's application orientation[4] and R&D strategy, etc.

Table 4: Other attributes characterizing the agents

Attribute name	Code	Scale type	Value
Application orientation	AO	Dichotomous	Basic research, Applied research
Absorptive capacity	AC	Ordinal	1, …, 10
Research attitude	RA	Dichotomous	Incremental, Radical
R&D strategy	RS	Dichotomous	Go-it-alone, Collaborative
Partner search strategy	PS	Dichotomous	Conservative, Progressive
Cooperation behavior	CB	Dichotomous	Imitative, Collective
Financial stock	FS	Ratio	
R&D infrastructure	I	Ordinal	1, …, 10

Agents use their knowledge characteristics to contribute to the creation of *inventions*[5]. In the model, inventions are called *R&D concepts*. We assume that an *R&D concept*[6] as a result of research projects consists of a small subset of the agents' kene sets and characteristics which are seen as key competencies. We assume that the generation of inventions, i.e. in the model the creation of R&D concepts, is embedded in processes of learning[7] by doing, learning by using, and learning by interacting (Andersen and Lundvall 1997, p. 254), and every simulation period that leads to a successful invention gives rise to an increase of the agent's expertise (E) level by one. Capabilities which are not used by the agents to create the R&D concept suffer declining expertise levels until eventually the respective E level may drop to zero. As a consequence, this capability is forgotten and eliminated from the agent's kene set (Pyka et al. 2002, p. 174). The same is valid for learning by interacting, i.e., only knowledge which is actively used by the agents in a partnership or a network, and

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[3] An agent's absorptive capacity (AC) refers to its ability to integrate pieces of external knowledge into its own knowledge stock during collaborative R&D (Fischer 2003, p. 344).

[4] research direction (Gilbert et al. 2007, pp. 102-103)

[5] An invention is a new idea before its commercialization (Fischer 2003, p. 344).

[6] The term R&D concept corresponds to the term innovation hypothesis used by Pyka et al. (2002, pp. 174-178)

[7] Learning is the acquisition and application of new information and skills and is considered as "a critical component in the development of continuous innovation for organizations" (Fischer 2003, p. 345).

an R&D concept is created, increases an agent's knowledge base.

Agents decide whether they prefer to do exclusively own R&D and therefore follow the go-it-alone strategy or they desire to cooperate and start looking for a partner. They might follow a conservative or progressive strategy in searching for cooperation partners. Whereas the conservative strategy implies a preference for potential partners with similar capabilities, progressive partner search concentrates on different capabilities (Gilbert et al. 2007, p. 103).

Collaboration might be realized according to an imitative or a collective strategy. While the first option excludes own research and focuses only on imitation, the latter collaborative strategy comprises in-house as well as joint research (Pyka et al. 2002, p. 176). With respect to potential partner search, the attractiveness of previous partners is the highest. A check of the potential partner's inventive capabilities is assumed to build the basis for the decision (Gilbert et al. 2007, p. 103). Cooperation experience is taken into account as past success and failures are reported (Pyka and Scholz 2008, pp. 6-13). Agents might choose to perform own research as well as to participate in R&D partnerships and networks simultaneously.

In addition, agents, partnerships or networks might opt for performing incremental or radical research. On the one hand, if an agent has enough capital, it can afford to do incremental research which involves R&D in the company's laboratories. One of the agent's capabilities is selected and changed according to the specific research direction of the agent. The related expertise level is marked down to one (Gilbert et al. 2001, pp. 5-7). If R&D is performed by a partnership or a network, the research direction held by the majority of the participating agents is chosen. In the course of the simulation, the research direction reacts to previous success as research continues towards the same direction or failure which comprises the selection of a completely different capability of its kene set. Alternatively, an agent opts for radical research if it faces the danger of bankruptcy. Therefore, it investigates entirely diverse market opportunities, generates a new capability (C) for its kene set, and creates a new R&D concept (Gilbert et al. 2007, pp. 102-103). Radical research performed by partnerships and networks are subject to the same process.

Interactions among Agents

Interdependencies among agents in the biotech innovation system are manifold. Figure 3 outlines the relations we consider between the main types of agents. Our model puts special emphasis on knowledge production and exchange processes among the agents. These processes are realized by the modification and exchange of kenes (see previous section), which is in some cases also compensated by money flows.

R&D cooperation between university agents and industry agents in Austrian biotechnology takes place in various ways: The most intensive knowledge flows between these agents are associated with the conduct of joint R&D that may lead to co-authored patents and academic papers. Competence centers, as institutionalized temporary research joint ventures, are taken into account as special cases of science and industry cooperation. Further knowledge flows arise through consulting and contract research that universities or research organizations perform for industry agents. Moreover, the performance of contract research may not only provoke knowledge flows but affects the financial stock as well. Consequently, money flows mainly from industry agents to research organizations and universities occur. Licensing agreements link firms to other agents that own patents, and are thus related with the transfer of explicit knowledge and require less personal contact (Schartinger et al. 2002, p. 305).

Labor mobility occurs mainly between the science and the industry sector, or through the hiring of university graduates by companies or research organizations. In Vienna's biotechnology sector, we observe less labor mobility within the industry sector, at least at the local level; in this case, major importance is attributed to international labor mobility (Tödtling and Trippl 2007, p. 361).

The creation of spin-off companies represents a particular knowledge flow linking academia with the business world. University members hold company stakes or create start-up companies (Schartinger et al. 2002, p. 305). Sometimes spin-off companies also grow out of companies or research organizations, consequently, facilitating knowledge flows.

Adjunct teaching is very common in the sector since biotech specialists and managers often give lectures in educational organizations. This channel is a rather formalized interaction type triggering personal contact and possibly the transfer of tacit knowledge. Knowledge interactions between companies and universities occur also during sabbatical periods and joint research programs, lectures held by firm members and biotech experts at universities. Moreover, synergies are achieved because companies use R&D infrastructure and university facilities, or rely on academic expertise and buy prototypes which have been developed at universities (Schartinger et al. 2002, p. 305).

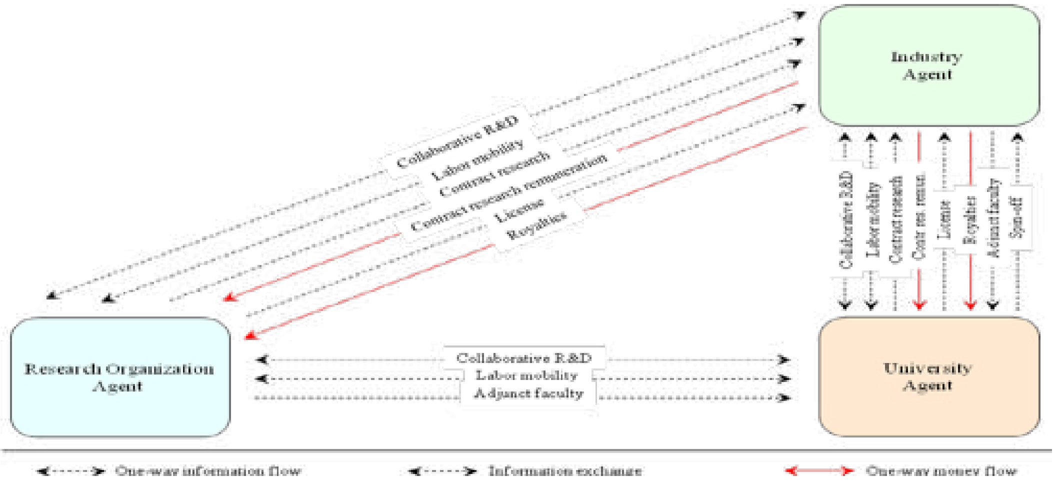

Figure 3: Agent types and their relations

Less formalized forms of knowledge interactions come from the joint supervision of master and PhD theses, the employment of graduates by industry agents, and the training of firm members. An intense transfer of tacit knowledge, without any formal agreements, occurs during conferences, informal meetings, and joint publications. In addition, the reading of publications and patents creates common knowledge in a certain field (Schartinger et al. 2002, p. 305).

Regarding knowledge exchange in joint R&D, we assume that agents interested in collaboration look for potential partners and inspect their qualities. Hereby, we further assume that there is an optimal cognitive distance for fruitful knowledge exchange (Nooteboom et al. 2007). The higher the number of capabilities the agents have in common, the more easily external knowledge is integrated into the own kene set. If both agents agree, the cooperation starts and the agents' kenes are modified as a result. The modification of the agents' kenes takes place as follows: If capability (C) is the same as the kene copied by the partner, the C with the highest expertise (E) level is selected from the set (Gilbert et al. 2001, p. 6). Due to the fact that integration of new, external knowledge is difficult (e.g. Cohen and Levinthal 1989), the E level of the respective C is downgraded to one (Pyka et al. 2002, p. 178). In the end, the agent and its partner have consolidated their kene sets used in the cooperative R&D output.

Networks in the model emerge from two different processes: they are either self-organized or policy-induced. On the one hand, networks of collaborating organizations develop out of repeated and persistent bilateral cooperation on the basis of individual decisions. In this case, agents are invited by network members, if they have been in former partnerships with them. The new member accepts this invitation if he has not yet become member of another network. Networks may decide to perform incremental or radical research as well as further collaboration like other agents (Pyka et al. 2002, p. 180). On the other hand, multilateral collaborative arrangements emerge through the provision of public funds that are issued through different types of funding (projects in bottom-up research and directed research programs, and more institutionalized forms of collaboration like competence centers). As is supported by the model, collaborative research fosters an easier access to new knowledge than individual research efforts of the agents.

Measuring System Performance in the Model

Agents (or, in case of collaborative research, groups of agents) create *R&D output* from their *R&D concepts.* Whereas an individual agent's R&D concept consists of a subset of its own kene set, a project group creates an R&D concept by choosing a subset of the project partners' joint kene set. If an R&D concept is successfully assessed by an evaluation device in the model, it obtains the status of an R&D output.

We distinguish two types of R&D output: *academic papers* or *patents* (Pyka and Scholz 2008, p. 10). Whether an R&D output is an academic paper or a patent is determined by the agent type of the producer: While a university agent aims for academic papers, an industry agent is assumed to go for patents, and a research organization agent has either option. In project groups, the majority of the agent types determine the R&D output, which is then shared by all project members without regard of agent type (e.g. a consortium that consists of three industry agents, one university agent, and one research organization agent performs R&D in order to apply for a patent). Every agent decides on performing R&D according to its own specific strategies and aims to increase the number and quality of R&D output items.

The attribution of value to the set of kenes in the R&D concept is necessary at different stages of the model and may take two different aspects into account: First, the *scientific value* of the R&D concept represents its novelty and is measured by its difference to existing kenes. This is accomplished by employing a concept of distance in capability space. Scientific evaluations happen during partner choice and proposal formation, or before public funding is granted. If the scientific value exceeds a certain threshold, the agent or the project group is allowed to continue the intended activity, i.e. the partnership commences, or the R&D concept is rewarded with the status of an R&D output. This kind of evaluation is also able to cover the case of direct top-down funding, where particular capabilities are favored for funding over other capabilities.

Second, the *financial value* of an R&D concept takes the (expected or actual) monetary reward into account. It is defined via an empirically calibrated fitness function $f(v_C, v_{CC}, v_E) f(v_C, v_{CC}, v_E)$, where v_C v_C, v_{CC} v_{CC}, and v_E are the monetary values attached to the kene characteristics capabilities (Cs), core competencies (CCs), and expertise (E). In order to account for the change of techno-economic opportunities, the fitness function is reshaped after each time-step (Pyka et al. 2002, pp. 175-176). Financial evaluations, on the other hand, take place during the application for venture capital, bank loans or when the agents reap the monetary paybacks from their R&D outputs. The rewards are allocated to the partners according to their relative involvement in the creation of the R&D concept, and according to their financial stock, i.e., the richer partners receive a higher proportion (Gilbert et al. 2001, p. 7). Moreover, cooperation experience (Pyka and Scholz 2008, p. 7) is memorized as it serves as a basis for decision-making in partner selection for collaborative activities. As mentioned above, the agents use the available information to carefully evaluate a potential partner.

Performance measurements also affect new firm generation. A particularly successful and profit-making incumbent attracts start-ups with slightly different knowledge endowments but with possibly differing strategies. This reflects the generation of variety as well as the diffusion of economically relevant know-how. So as to represent the lack of experience and initial capital, the start-up's expertise level and financial stock are low (Gilbert et al. 2007, pp. 103-104). While at the beginning a start-up company is dependent on public RTI funding, later it is able to attract private investors as well.

Additionally to the number of patents and academic papers, the creation of high-tech jobs will be monitored. Due to the fact that patenting reflects the R&D organization's expectations which are often not fulfilled, it is not enough to rely on the number of patents as a unique indicator. As every indicator is generally arguable and restricted, we decided to introduce a complementary indicator, the creation of high-tech jobs. Whereas the number of patents and academic papers are to a high degree specific and arbitrary, this system variable allows measuring the performance from a dynamic perspective at a macro-level and reflects the potential for future output. It results from agents' attributes, such as the number of R&D personnel employed by the organizations as well as the expertise levels specifying their capabilities, or the agents' turnover. The creation of high-tech jobs reflects not only the sector's performance over time but it also represents the benefits of public RTI funding efforts for the national economy. Therefore, accumulated values of several attributes (e.g. the creation of start-ups) should be surveyed. Given that academic papers and patents reflect conducted research, these indicators together with the creation of high-tech jobs characterize the development of the biotech innovation system

The Role of Public RTI Funding

As we ultimately intend to simulate different public RTI funding regimes facing the complexity of the biotech innovation system, emphasis is laid on the role of public RTI funding in the system. Public RTI policy in Austria in the last few years has put considerable weight on indirect funding, i.e., tax incentives for R&D. Institutional funding by the government is to a large extent absorbed by universities, while the non-profit research sector is small in an international comparison. Direct funding (government programs) exists on national as well as at regional levels, and includes measures supporting R&D collaboration, and also a more institutionalized form of collaboration between science and industry, so-called competence centers, which are relevant for the life sciences sector in Vienna.

Public funds comprise institutional funding granted specifically to science agents, whereas program and project funding goes to science as well as to industry agents. In a recent analysis of R&D networks in the Vienna life sciences sector, 136 projects in eight funding programs were identified. Out of this number, two programs are European, namely the *Life Quality* program in the 5th EU framework program as well as *Medical and Biotechnology* in EUREKA. The national funding activities comprise the Austrian NANO initiative, the GEN-AU Genome Research Austria (GEN-AU 2009) in addition to five specific competence centers. To be emphasized here is the fact that Viennese organizations are largely involved in European projects (87%), and less at a national (6%) or regional (7%) level (Heller-Schuh and Paier 2009, p. 162).

In the case of Austrian biotech, various types of joint R&D are considered as fruitful although one of the major drawbacks is red tape, i.e., the involvement in bureaucratic and non-research activities. Generally, it is often criticized that the funding system in Austria is too complex and confusing, and that for some research stages (e.g. clinical research phase 2) funding is not provided at all. Specifically, the nonexistence of standardized contracts, fundraising, and accounting for funding institutes claim considerable time which could be used for core business (life-science.at 2008). Public RTI policy at the regional level aims to improve possibilities offered to resident companies and organizations regarding access and use of funding support, and promote regional innovation potential (Cooke 2002b, p. 133). For a localized sectoral innovation system like the Vienna biotech sector, it is important how effective public interventions are in the creation of sustainable dynamics within the cluster and its relations with the outside world.

It is the main goal of this modeling exercise to analyze and compare the effects of different funding types in a localized biotech innovation system regarding collaborative and innovative performance. Hereby, the various types of direct funding – with or without requirement for inter-organizational cooperation – will be compared to indirect funding (tax incentives) and also to the case of inexistent policy intervention.

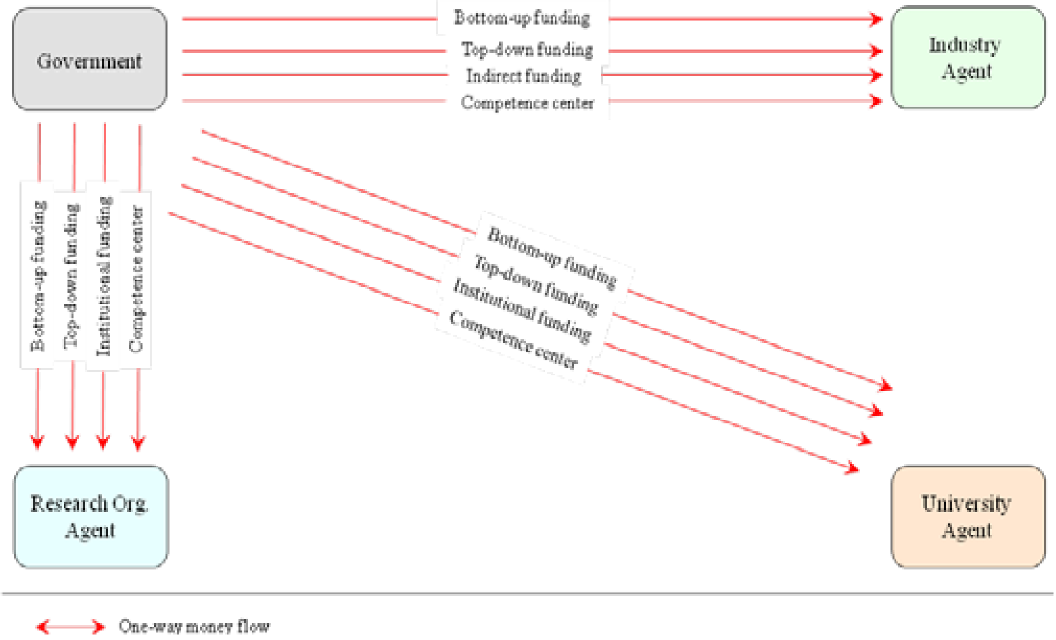

Figure 4: Public RTI funding as a financial resource

Government-funding for R&D with the requirement to cooperate triggers the structure of collaboration networks which influences the agent-specific knowledge output in a dynamic way. This belief has governed RTI policy throughout Europe in the last decades, and it continues to do so as well at the regional level. As illustrated above in Figure 4, public RTI funding realizes money flows from the *government* component to industry, university and research organization agents.

In the model, government provides not only funding for programs and projects for science as well as industry agents but also university agents and research organization agents with institutional funding. In contrast to indirect R&D funding which benefits all industrial agents as long as they perform R&D, direct funding exerts a stronger governance effect by taking the knowledge endowments of submitted proposals into account. It is thus expected to steer the innovation process with regard to the direction of research on the agent as well as at the system level. Government knows the once submitted or published kenes of all agents and serves somehow as an autonomous agent making funding decisions. This concept covers also the process of lobbying by agents. Thus, governmental intervention improves to some extent the *innovation oracle* that has been used in other ABMs of innovation (Pyka et al. 2002, pp. 175-181).

Conclusions and Outlook

Agent-based modeling begins with assumptions about agents and their interactions and then uses computer simulations to generate individual *histories* that can reveal the dynamic consequences of these assumptions. With the assumptions made we can investigate how macro-scale effects measured in terms of patents, academic papers, and the creation of high-tech jobs arise from micro-processes of interactions among many agents.

In our model, these agents represent universities, research organizations, and companies in the biotech field. We conceptualize the biotech innovation system as an agent system comprising knowledge production and exchange processes among the agents and the production of individual and joint output. Financial resources and government intervention serve as inputs, thus creating a playground for policy simulations in order to figure out the impact of public RTI funding on the innovative performance of the system.

At later stages, particular emphasis will be laid on the assessment of the conceptual framework and the model's wider applicability while comparing the model's results with empirical data. The empirical context for the computer simulation will be the life sciences cluster in the Vienna region.

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